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STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES

Report 12

CREDIBLE EARTHQUAKES FOR THE CENTRAL UNITED STATES

by

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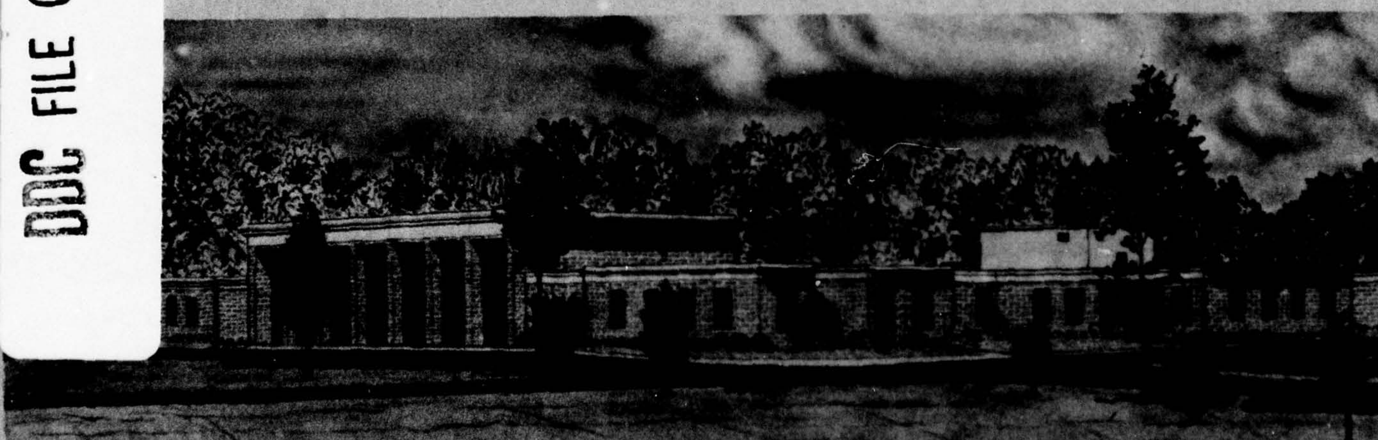
December 1978

Report 12 of a Series



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20. ABSTRACT (Continued).

special study will be required for establishing credible ground-motion values for sites near the boundaries. A maximum-magnitude earthquake is determined for each zone, as well as a magnitude-recurrence equation. Using the Murphy-O'Brien formulation, as well as theoretical results of Herrmann and a limited amount of strong-motion data for the central United States, equations are derived for that region which relate maximum horizontal acceleration and velocity to body-wave magnitude and epicentral distance.

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PREFACE

This report was prepared by Drs. O. W. Nuttli and R. B. Herrmann, Department of Earth and Atmospheric Sciences, St. Louis University. It is part of ongoing work at the U. S. Army Engineer Waterways Experiment Station (WES) in Civil Works Investigation Study, "Methodologies for Selecting Design Earthquakes," sponsored by Office, Chief of Engineers, U. S. Army.

Preparation of this report was under the direction of Dr. E. L. Krinitzsky, Engineering and Rock Mechanics Division (EG&RMD), Geotechnical Laboratory (GL). General direction was by Mr. J. P. Sale, Chief, GL, and Dr. D. C. Banks, Chief, EG&RMD.

COL J. L. Cannon, CE, and Mr. F. R. Brown were Director and Technical Director, respectively, of WES during the period of this study.

CONTENTS

STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES

CREDIBLE EARTHQUAKES FOR THE CENTRAL UNITED STATES

PART I: THE CONCEPT OF THE CREDIBLE EARTHQUAKE

1. In general there are two methods for estimating the earthquake-induced ground motion at a specific site. The one is deterministic, the other probabilistic. In the deterministic procedure one estimates the location and size of the earthquake of interest and then attenuates the source motion to the desired site. The resulting motion, which may be given as a time history, a response spectrum, or a set of ground-motion values (e.g., peak acceleration, peak ground velocity, peak displacement and bracketed duration) is called the credible earthquake motion. For critical structures, such as nuclear power plants and dams, whose failure could result in great loss of life and injury, as well as large economic loss, it is customary to assume that the credible earthquake occurs at the closest point to the site from the fault or the earthquake source region, and that the magnitude of the earthquake is the maximum which can be expected for the fault or for the source region.

2. For the probabilistic method one must identify the extent of all the earthquake source regions which can affect the site, and in addition must determine both the maximum-magnitude earthquake

which can occur in each source region and the magnitude-frequency recurrence rate of earthquakes for each source region. This information, together with a knowledge of the attenuation of wave energy for the region in question, can be used to make a probabilistic statement concerning the ground motion at the site, e.g., that there is a 10% probability that a horizontal ground acceleration as large as 0.25g will occur at the site in a 200-year period. The engineer, on the basis of his estimate of the criticalness of the structure and its expected lifetime, assigns the probability level and the time period and obtains from the analysis the ground-motion value which has that probability of occurrence in that selected number of years.

3. Both the deterministic and the probabilistic methods require that the seismic source zones be identified, that the maximum-magnitude earthquake for each source zone be estimated, that the magnitude-frequency recurrence rate for each source zone be determined and that the attenuation of seismic wave energy with distance be known as a function of wave frequency. A major part of this state-of-the-art report will be devoted to fulfilling these tasks for the central United States. (The central United States is defined as the area bounded on the west by the Rocky Mountain front and on the east by the Appalachians, excluding both mountain systems themselves.) Thus the information contained in this report forms the basis for either deterministic or probabilistic assessment of earthquake ground motion in the central United States.

4. In keeping with the current practice of the Chief of Engineers and the Waterways Experiment Station of the Corps of Engineers, in this report the credible earthquake is taken to be the maximum-magnitude earthquake occurring at the nearest point in the source region to the site. If there are n source regions affecting the site, the effect of each of the n credible earthquakes must be considered in the process of defining the site specific credible earthquake. This study will define and provide justification for the maximum-magnitude earthquake for a source region as being the magnitude of the earthquake which has a 1000-year recurrence interval, or a 63% probability of occurring in a 1000-year period of time. Justification for this definition will be given in Part IV: Regional Identification of Credible Earthquakes.

PART II: SOURCES OF INFORMATION ON CENTRAL UNITED STATES SEISMICITY

Felt Earthquakes

5. The history of earthquake activity in the central United States begins with its settlement, which in some areas dates back to the eighteenth century and in others to as recently as the late nineteenth century. During the latter quarter of the nineteenth century and subsequently, the U.S. Weather Bureau, the U.S. Coast and Geodetic Survey, and related organizations in the Department of Commerce and the U.S. Geological Survey have published annual lists

of earthquake activity. In general these included all earthquakes large enough to be felt by people, except in rural, sparsely populated areas where no reports were made of earth tremors. Prior to the late 1800's the historical record of earthquakes consists principally of newspaper accounts, and to a lesser extent of diaries and other personal accounts. Thus the record is incomplete, particularly for the smaller felt earthquakes. However, because of the large felt area associated with central United States earthquakes of body-wave magnitude 5 and greater, it is unlikely that any earthquakes of that size escaped attention since 1800.

6. Seismographs were first installed in the central United States in the first decade of the twentieth century. The early instruments were few in number and had a low magnification, so they detected only earthquakes strong enough to be felt by people, and not nearly all of them. In the 1930's Saint Louis University developed a limited network of seismograph stations in the central Mississippi valley, whose threshold of detectability (but not location ability) was about the smallest earthquake that could be felt by humans. The network provided valuable information on the velocities of seismic waves and better epicentral locations than simple felt reports. The next major step in the development of seismographic coverage of the central United States came in the 1960's, when the World-Wide Standard Seismograph Network was installed. The stations of this network,

although limited in number, had calibrated high-gain instruments with excellent time control. They provided valuable information on ground amplitudes and periods, and thus furnished the first usable material for determining the attenuation of seismic wave motion and for estimating magnitudes of earthquakes. Early in the 1970's microearthquake networks have been installed in a number of seismic source regions of the central United States. They have the capability of detecting the low magnitude, more frequently occurring earthquakes that are too small to be felt by man.

7. In order to assess the seismicity of a region, one must quantitatively describe the size of an earthquake as well as give its date, origin time and geographic location. In this report the body-wave magnitude, m_b, shall be used as the measure of the size of the earthquake. Since about 1962 body-wave magnitudes can be assigned to central United States earthquakes on the basis of the records of ground motion made by calibrated seismographs. Prior to that time, however, such data are lacking, and the magnitudes must be estimated by the effects of the earthquakes on people and on structures, i.e., by their Modified Mercalli (MM) intensity relations. Nuttli[1] developed a method for estimating m_b from the observed attenuation of MM intensity with distance for a given earthquake. He applied the method to the three principal earthquakes of the 1811-1812 sequence near New Madrid, Missouri. Since then Nuttli _et al_[2] have refined the methodology for determining m_b from intensity attenuation, and have

applied it to a number of earthquakes. This method works best for large historical earthquakes, of m_b equal to or greater than 5, for which adequate intensity data are available. It is estimated to give m_b values to $\pm$ 0.2 units, as good as can be obtained from seismographic data. For smaller earthquakes Nuttli and Zollweg[3] developed a relation between m_b and felt area, based on the data of recent earthquakes. This equa tion can be used for historical earthquakes for which the felt areas are known. It is estimated to give m_b values to $\pm$ 0.3 units. Finally, there are many earthquakes for which only the epicentral intensity is known. For these Nuttli[4] established an empirical relation between m_b and epicentral intensity, based on data of recent earthquakes for which both quantities are known. This method is estimated to give m_b values to $\pm$ 0.5 units.

Microearthquakes

8. Microearthquakes are small magnitude earthquakes which cannot be felt by humans. They occur more frequently than larger magnitude earthquakes, so that in a relatively short time observation of them will yield useful seismological data. For example, they serve to outline the active fault zone, both laterally and with depth. They provide information on seismic wave velocity, and on the attenuation of the high frequency waves which principally are responsible for damage to structures. They also are useful for determining the predominant focal mechanism of the seismic region, which is related to

the state of stress and which provides information on the type of faulting, the strike and dip of the fault plane and the orientation of the slip motion. Finally, microearthquake data can be used to extend the magnitude-recurrence curve to the smaller magnitudes and thus give a better value of its slope and intercept.

9. The microearthquake network installed by Saint Louis University in southeast Missouri, northeast Arkansas, western Tennessee, western Kentucky and southern Illinois in 1974 was the first of its kind in the central United States. Figure 1 shows the location of the seismograph stations and the epicenters of the located earthquakes. From the figure the New Madrid fault zone is clearly outlined. It consists of a long southwest branch, of a very active central zone, and of a northeast-trending branch. Prior to the installation of the microearthquake network the New Madrid fault zone was thought to be broader and more diffuse. Now a main trend can be identified, although there are subparallel and other trends indicated by the data which broaden the earthquake source zone.

10. Since 1977 a number of additional microearthquake networks have been installed for the purpose of increasing knowledge of earthquake processes in the central United States. They include the Anna, Ohio region, the Wabash valley region, the states of Oklahoma and Kansas, and a small array in central Minnesota. At present the number of microearthquakes detected by these networks is insufficient

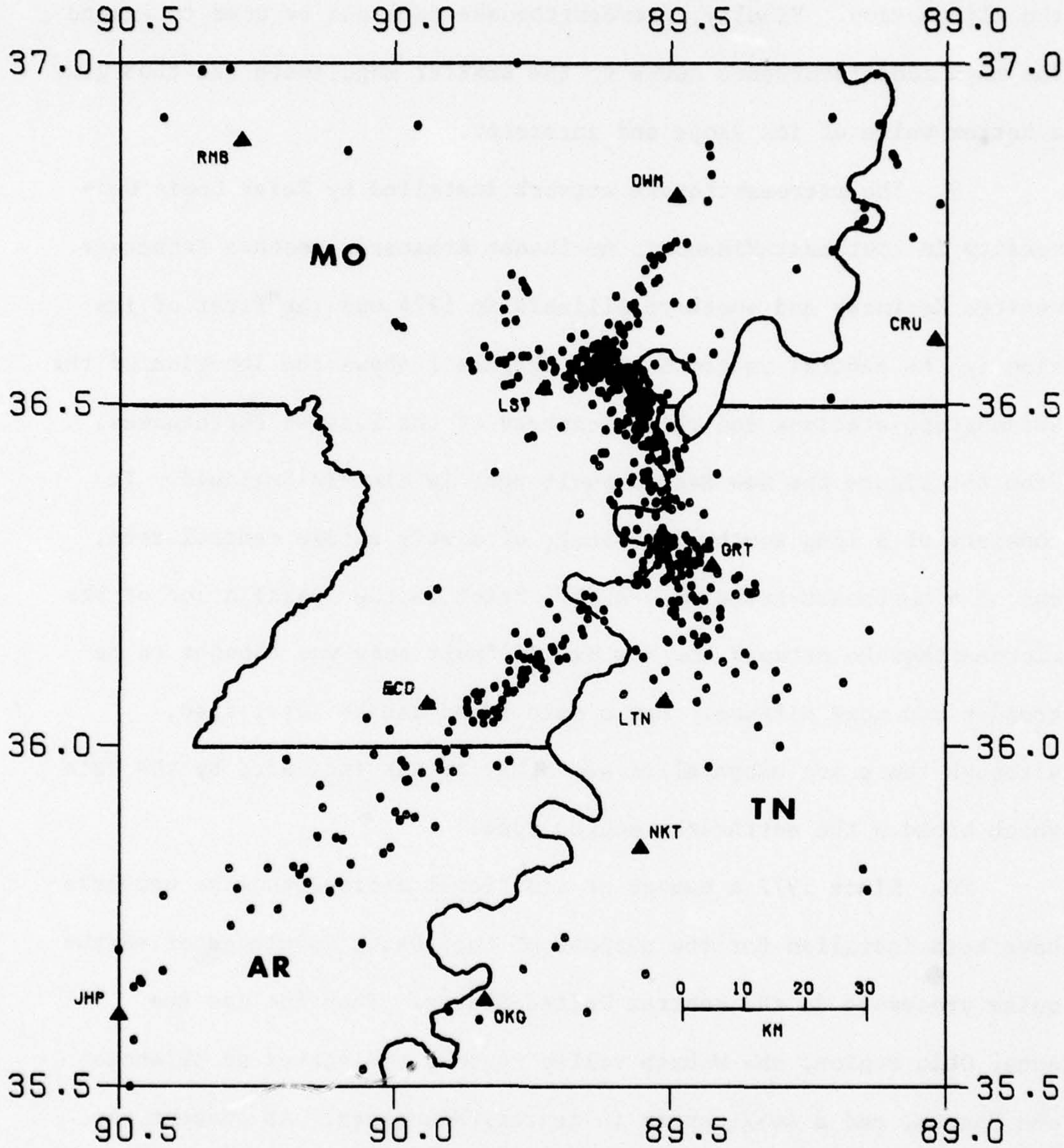

Figure 1. Earthquakes located in the central Mississippi valley between 1 July 1974 and 31 March 1978. Triangles indicate seismograph stations. Small circles indicate earthquake epicenters

to draw any conclusions about the location of active fault zones in those regions. Due to the low rate of seismic activity, these arrays may have to operate for decades before a seismicity pattern as distinct as that shown in Figure 1 may be found.

1811-1812 New Madrid Earthquakes

11. The sequence of earthquakes that began in the central Mississippi valley on 16 December 1811 was unique, in regards to the magnitudes of the earthquakes, the number, size and duration of the aftershocks and the large damage and felt areas of the three major earthquakes of the sequence. Fuller[5] described the physiographical effects of the earthquakes and Nuttli[1] the intensity distributions, magnitudes and ground motion. Recently, Nuttli *et al*[2] estimated the body-wave magnitudes of the three principal earthquakes to be 7.35 (16 December 1811), 7.2 (23 January 1812) and 7.5 (7 February 1812). The body-wave magnitude scale is saturated at these values. That is, no earthquake can have an m_b value greater than about 7.5. Thus these earthquakes represent truly major events, similar to the great earthquakes occasionally associated with movements along lithospheric plate boundaries.

12. According to Fuller[5], aftershocks continued until at least 1817. However, records of the number and size of the aftershocks were only kept for the three-month interval 16 December 1811 to 15 March 1812. During that time there were 207 damaging earthquakes, of m_b 5

or greater, and an additional 1667 that were large enough to be felt over an area of more than one county[1]. Thus the 1811-1812 earthquakes provide dramatic evidence of the earthquake hazard which exists in the central United States.

Seismicity Map of Central United States

13. Figure 2 presents a map showing the epicenters of all known felt earthquakes (or earthquakes of $m_b \geq 3$) for the central United States through the year 1975. Excluded from the map are the thousands of aftershocks of the 1811-1812 earthquakes. The size of the symbol used in plotting the epicenters is proportional to the body-wave magnitude. In cases where several earthquakes had the same epicenter, they were plotted adjacent to each other in an area 10 km by 10 km, which is smaller than the area of uncertainty of location of most events. In cases where the 10 km by 10 km area became filled, the remaining epicenters were not plotted. This happened most frequently in the New Madrid seismic zone.

14. Data sources for Figure 2 and for the tables in Part III include Earthquake History of the United States[6], United States Earthquakes[7] for the years 1925 through 1972, Preliminary Determination of Epicenters[8] for the years 1972 through 1974, Earthquakes of the Stable Interior, with Emphasis on the Midcontinent[9], A Contribution to the Seismic History of Missouri[10], Seismological Notes[11] for the years 1911 through 1975, Quarterly Seismological Bulletin of Saint Louis

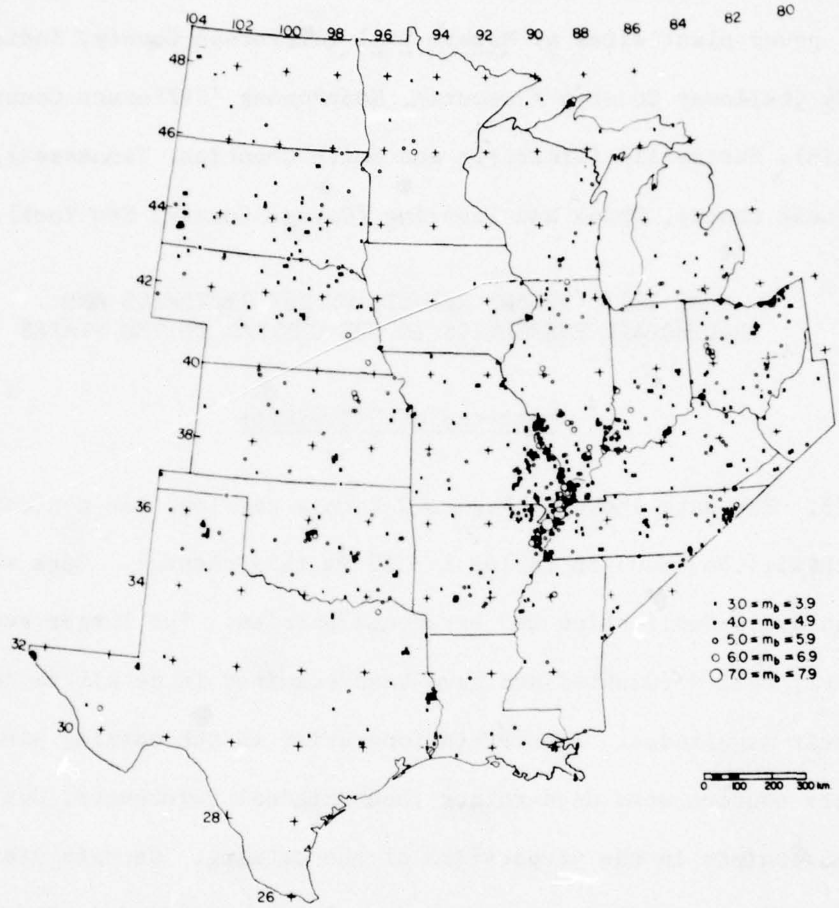

Figure 2. Map of felt earthquakes, or earthquakes of m_b = 3.0 or greater, for the central United States from historic times through 1975

University[12] for June 1974 through December 1975, unpublished lists of earthquakes compiled by J.E. Zollweg of Memphis State University, a list of earthquakes compiled by M.M. Varma and R.F. Blakely of Indiana University and the Preliminary Safety Analysis Reports for proposed nuclear power plant sites at Marble Hill (Jefferson County, Indiana), Calloway (Calloway County, Missouri), Koshkonong (Jefferson County, Wisconsin), Hartsville (Trousdale and Smith Counties, Tennessee), Perry (Lake County, Ohio) and Sterling (Cayuga County, New York).

PART III: RECENT RESULTS ON THE TECTONICS AND EARTHQUAKE ENERGETICS IN THE CENTRAL UNITED STATES

Patterns of Seismicity

15. The data shown in Figure 2 form a catalog, the contents of which will be found in Tables 1 - 10 in this chapter. Care was taken to avoid duplication and erroneous entries. The larger events are fairly well-documented and have been examined in detail to determine their magnitudes. Interpretations exist in the catalog since secondary sources were used rather than original references, due to time constraints in the preparation of the catalog. Certain statistical tests of the completeness of the catalog are applied in Part IV: Regional Identification of Credible Earthquakes.

16. The distribution of earthquake epicenters in Figure 2 and knowledge of the tectonic features of the central United States make it possible to identify the principal earthquake source zones.

Figure 3 shows the location and extent of these seismic source regions. The boundaries of the source zones are not as distinct as indicated. Rather, they represent regions in which damaging earthquakes have been known to occur. The boundary lines were selected in part for ease of the computer search. Thus, in designing for the ground motion at a specific site, judgment must be used if the site is near the boundary of a source zone. That is, the magnitude of the credible earthquake near the boundary of a source zone may, depending on individual circumstances, have a value as large as that of the maximum-magnitude earthquake for the source zone to as small as that of the maximum-magnitude earthquake associated with residual events. The coordinates of the source zones are given in Appendix A.

17. The Anna, Ohio seismic zone is an area of Ohio which has experienced five earthquakes in the m_b range of 5.0 to 5.3 since 1875. It includes the area where the north-south trending Cincinnati arch bifurcates into the northeast trending Findlay and northwest trending Kankakee arches. Although no definite correlation between the structural features and the earthquake activity has been established, it seems possible that the arches could be responsible for locally modifying the uniform continental compressive stress field expected from plate tectonic theory, so as to cause stress concentrations and subsequently earthquakes. Table 1 lists the earthquakes in the Anna zone. The column headings are: earthquake date, origin time in Universal Time (OT), latitude (LAT) and longitude (LON) of epicenter,

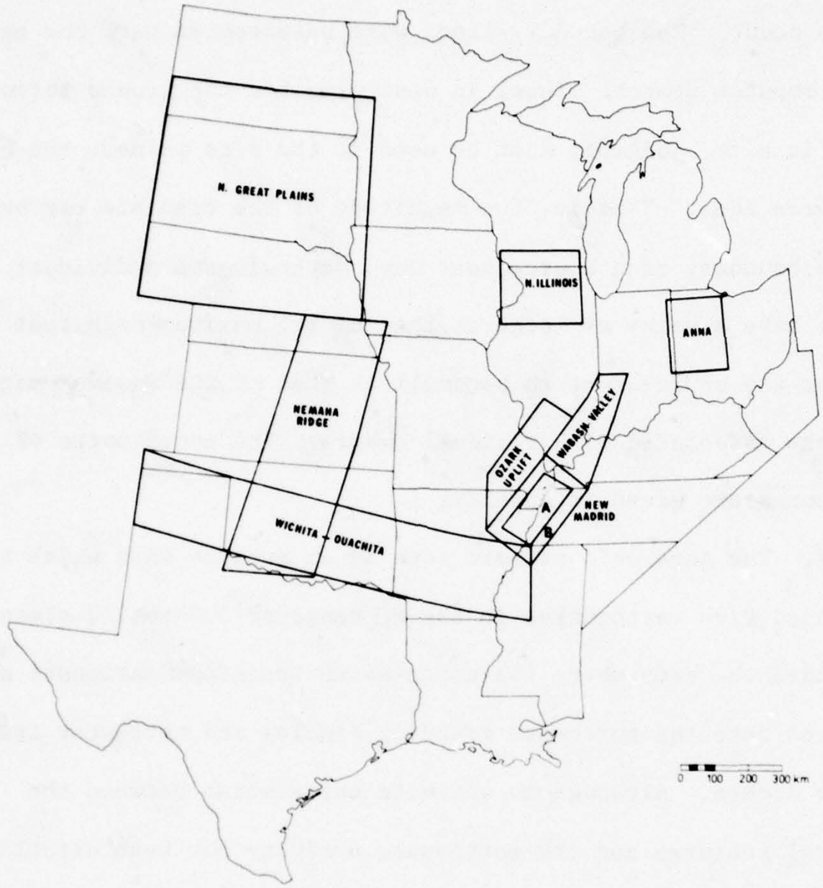

Figure 3. Seismic source zones of the central United States. Note that the boundaries of the seismic source zones are only approximate. For sites near the boundary of a seismic source zone independent study must be carried out to determine if the sites actually belong in the source zone rather than in the surrounding, less active "Residual Events" zone, which encompasses all of the central United States outside of the outlined source zones

Table 1 **THIS PAGE IS BEST QUALITY PRACTICABLE FROM COPY FURNISHED TO DDC**

SOURCE REGION ANNA,OHIO
AREA= 37605 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA		IO	MB	MS
00 00 1845	00 00 00	41.1	84.2	0		2	3.0	
04 23 1873	04 14 00	39.7	84.2	0	3	4	3.6	
06 18 1875	13 43 00	40.2	84.0	100000		7	5.3	
06 00 1876	00 00 00	40.4	84.2	0		0	4.2	
02 09 1882	20 00 00	40.4	84.2	250		5	4.2	
03 31 1884	19 00 00	39.5	84.7	0		2	3.0	
09 19 1884	20 14 00	40.7	84.1	320000		6	4.7	
12 23 1884	23 00 00	40.4	84.2	0		3	3.4	
09 00 1889	00 00 00	40.4	84.2	0		3	3.4	
03 15 1896	07 00 00	40.3	84.2	0		4	3.8	
04 23 1906	07 12 00	40.7	83.6	0		5	4.2	
00 00 1914	00 00 00	40.4	84.2	0		3	3.4	
03 27 1925	04 06 00	39.5	83.9	0		5	4.2	
10 00 1925	00 00 00	40.4	84.2	0		3	3.4	
10 27 1928	00 00 00	40.4	84.1	250		3	3.4	
03 08 1929	09 06 00	40.4	84.2	13000		5	4.2	
06 26 1930	21 45 00	40.5	84.0	0		4	3.8	
06 27 1930	07 23 00	40.5	84.0	0		4	3.8	
07 11 1930	00 15 00	40.6	83.2	0		4	3.8	
09 29 1930	21 15 00	40.4	84.2	0		3	3.4	
09 30 1930	20 40 00	40.3	84.3	0		7	5.3	
10 00 1930	00 00 00	40.4	84.2	0	3-	4	3.6	
03 21 1931	15 48 00	40.4	84.2	0		3	3.4	
04 01 1931	00 15 00	40.4	84.0	0		3	3.4	
06 10 1931	08 30 00	41.3	84.0	4000		5	4.2	
09 20 1931	23 04 54	40.4	84.2	120000		7	5.3	
10 08 1931	14 30 00	40.4	84.2	0		3	3.4	
02 23 1933	03 20 00	40.3	84.2	5000		4	3.8	
01 31 1936	19 30 00	41.2	83.2	0		4	3.8	
01 31 1936	20 00 00	41.2	83.2	0		2	3.0	
03 02 1937	14 47 36	40.4	84.2	280000		7	5.3	
03 03 1937	09 50 00	40.7	84.0	500		5	4.2	
03 03 1937	09 55 00	40.7	84.0	0		3	3.4	
03 09 1937	05 44 33	40.4	84.2	500000	7-	8	5.3	
04 23 1937	17 15 00	40.7	84.0	650		3	3.4	
04 27 1937	17 00 00	40.7	84.0	650		3	3.4	
05 02 1937	17 05 00	40.7	84.0	0		4	3.8	
03 18 1939	00 00 00	40.4	84.0	0		2	3.0	
03 18 1939	14 03 00	40.4	84.0	1400	3-	4	3.6	
06 18 1939	03 20 00	40.3	84.0	1000		4	3.8	
07 09 1939	12 50 00	40.3	84.0	0		2	3.0	
11 13 1944	11 52 00	40.4	84.4	45000		3	4.3	
04 20 1950	00 00 00	39.8	84.2	0		4	3.8	
01 27 1956	12 03 00	40.4	84.2	5000		5	4.2	
02 22 1961	06 45 00	41.2	83.3	13000		5	4.2	
07 26 1968	00 00 00	40.4	84.2	0	2-	3	3.2	
09 29 1974	02 26 17	41.2	83.4	0		2	3.0	

felt area in km^2 (a zero indicates felt area is not known), epicentral intensity (IO), body-wave magnitude (MB) and surface-wave magnitude (MS).

18. The North Illinois seismic zone is an area of northern Illinois and southern Wisconsin which has experienced a few moderate-sized earthquakes. The east-west trending Sandwich fault lies within the region, but there is no demonstrated relation between the fault and occurrence of earthquakes. Table 2 lists the earthquakes in the zone.

19. The Northern Great Plains seismic zone includes southern North Dakota, South Dakota, northern Nebraska and western Minnesota. Seismic activity is spread throughout the zone, with no apparent relation to tectonic features. The amount of earthquake activity is greater than in surrounding areas which are not assigned to a specific zone. Table 3 lists the known earthquakes which occurred within the zone.

20. The Nemaha Ridge seismic zone takes its name from the major north-south trending structural uplift of eastern Oklahoma, eastern Kansas and eastern Nebraska. The southern limit of the Nemaha Ridge seismic zone is indefinite. In Figure 3 it overlaps the cross-trending Wichita-Ouachita zone. Table 4 lists the known earthquakes in the Nemaha Ridge zone.

21. The Wichita-Ouachita source region is a zone over 1000 km long extending in an east-west direction from central Mississippi to

TABLE 2

SOURCE REGION NORTHERN ILLINOIS
AREA= 55126 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
05 27 1881	00 00 00	41.3	89.1	0	4	4.7	
11 28 1907	16 30 00	42.3	89.8	250	4	3.8	
11 28 1908	00 00 00	42.2	89.8	0	4	3.8	
05 26 1909	14 42 00	42.5	89.0	800000	7	5.3	
10 22 1909	22 30 00	41.8	89.7	0	4- 5	4.0	
01 02 1912	16 21 00	41.5	88.5	150000	6	4.7	
09 25 1912	00 00 00	42.3	89.1	0	3- 4	3.6	
10 17 1913	02 15 00	41.8	89.7	10000	3- 4	3.6	
01 23 1928	09 19 00	42.0	90.0	1000	4	3.8	
12 07 1933	05 55 00	42.9	89.2	1200	4	4.2	
11 12 1934	14 45 00	41.5	90.5	13000	6	4.7	
01 05 1935	18 40 00	41.5	90.6	500	4	4.2	
01 05 1935	18 45 00	41.5	90.6	0	3	3.4	
11 08 1938	05 30 00	42.5	90.7	0	0	3.0	
11 08 1938	07 15 00	42.5	90.7	0	0	3.0	
11 08 1938	09 30 00	42.5	90.7	0	0	3.0	
11 24 1939	19 45 00	41.6	90.6	0	2- 3	3.2	
03 01 1942	14 43 10	41.2	89.7	10000	4- 5	4.0	
03 16 1944	00 00 00	42.0	88.3	0	4	3.4	
03 16 1947	15 30 00	42.1	88.3	0	4	3.8	
09 15 1972	05 22 16	41.6	89.4	200000	6	4.4	3.3

Table 3

SOURCE REGION NORTHERN GREAT PLAINS
AREA= 426723 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
02 09 1872	00 00 00	44.6	100.7	0	3	3.4	
10 09 1872	16 00 00	42.7	97.0	8000	5	4.2	
08 17 1876	05 25 00	44.1	99.6	0	4	3.8	
11 15 1877	17 45 00	41.0	97.0	450000	7	5.3	
12 29 1879	06 30 00	42.9	97.3	0	5	4.0	
03 17 1884	20 00 00	41.1	100.7	0	4	3.8	
10 11 1895	23 55 00	43.9	103.3	4000	5	4.2	
10 12 1895	01 25 00	43.9	103.3	4000	5	4.2	
02 04 1896	11 45 00	42.6	97.3	0	3	3.4	
09 16 1898	09 59 00	42.6	97.3	0	4	3.8	
12 06 1899	12 00 00	44.5	99.0	10000	4	3.8	
07 28 1902	18 00 00	42.5	97.5	90000	5- 6	4.5	
12 01 1904	09 00 00	41.8	96.7	0	3	3.4	
05 10 1906	00 27 00	43.0	101.3	45000	6	4.7	
01 26 1909	20 15 00	42.3	97.8	2500	4- 5	4.0	
02 26 1910	08 00 00	41.4	97.4	0	4- 5	4.0	
06 02 1911	22 34 00	44.2	98.2	100000	5	4.5	
09 16 1915	19 00 00	42.8	99.3	0	3- 4	3.6	
10 23 1915	06 05 00	43.8	101.5	0	5	4.2	
02 24 1916	04 30 00	43.0	102.5	0	3	3.4	
06 29 1916	07 45 00	43.4	99.9	0	3	3.4	
12 00 1916	00 00 00	41.5	100.5	0	2- 3	3.2	
07 14 1920	23 00 00	43.2	103.2	4000	3	3.7	
03 16 1921	23 45 00	43.5	96.7	0	3- 4	3.6	
09 24 1921	00 30 00	43.7	98.7	0	4	3.8	
01 02 1922	14 50 00	43.8	99.3	0	6	4.7	
09 10 1923	06 30 00	41.7	96.2	0	3- 4	3.6	
12 30 1924	22 10 00	43.5	103.5	18000	4	3.8	
08 25 1925	06 27 00	42.8	97.4	0	4	3.8	
04 30 1927	04 15 00	46.9	102.1	0	2	3.2	
10 14 1927	16 10 00	41.6	98.9	1000	4	3.8	
11 16 1928	13 45 00	44.1	103.7	5000	5	4.2	
10 06 1929	12 30 00	42.8	97.4	1800	5	4.2	
01 17 1931	18 45 00	43.7	98.7	0	4	3.8	
08 08 1933	00 00 00	41.9	103.7	0	4- 5	4.0	
01 29 1934	12 30 00	45.9	97.7	0	4	4.2	
05 11 1934	10 40 00	41.5	98.7	2500	4	3.8	
07 30 1934	07 20 00	42.2	103.0	60000	6	4.7	
08 30 1934	03 50 00	43.4	99.1	0	4	3.6	
11 08 1934	04 45 00	42.6	100.2	3000	3	3.4	
11 01 1935	10 00 00	44.0	96.6	0	3	3.4	
10 30 1936	10 30 00	43.5	103.5	0	4	3.8	
01 02 1938	17 05 00	44.5	98.2	8000	4- 5	4.0	
03 24 1938	13 11 00	42.7	103.4	5000	4	3.8	
10 01 1938	22 15 00	43.8	99.3	23000	5	4.2	
10 11 1938	09 37 00	43.5	96.7	20000	5	4.2	
11 01 1938	22 10 00	43.2	98.9	5000	4	3.8	
06 10 1939	18 30 00	43.0	98.9	0	4	3.8	
05 25 1941	06 25 00	43.5	103.5	20000	4- 5	4.0	
03 11 1942	16 55 00	44.4	103.5	0	3- 4	3.6	
05 16 1943	19 40 00	43.5	103.5	0	4	3.8	

(Continued)

Table 3 (Concluded)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
11 10 1945	09 00 00	43.0	97.9	0	4	3.8	
07 23 1946	06 45 00	44.1	98.6	22000	6	4.7	
05 14 1947	05 02 00	46.0	100.9	0	4	3.8	
05 16 1947	05 45 00	44.4	100.3	0	3- 4	3.6	
08 25 1947	14 00 00	43.1	98.9	0	4	3.8	
04 07 1948	00 00 00	41.4	99.6	0	2- 3	3.2	
05 07 1949	14 54 10	44.5	99.0	0	3	3.4	
05 13 1949	04 15 00	42.5	99.0	3000	4	3.8	
06 03 1949	00 00 00	45.0	100.0	0	4	3.8	
12 14 1949	03 15 00	43.2	99.4	0	3	3.4	
11 15 1952	00 00 00	44.1	103.5	0	4	3.8	
12 21 1953	22 43 00	45.2	102.9	0	3- 4	3.6	
12 31 1953	20 30 00	43.1	99.3	0	4	3.8	
02 25 1955	01 45 00	41.3	98.6	3000	4	3.8	
12 03 1957	07 30 00	43.8	98.2	250	4	3.8	
01 12 1959	13 00 00	44.9	98.1	0	4	3.8	
12 31 1961	16 35 59	44.4	100.3	34000	5- 6	4.5	
03 09 1963	15 25 00	42.8	103.0	0	2- 3	3.2	
03 24 1964	06 12 00	43.5	103.5	4000	5	4.2	
03 28 1964	10 08 45	42.8	101.7	270000	7	4.7	
03 28 1964	10 24 50	42.8	101.7	0	0	3.6	
08 26 1964	16 58 52	43.8	102.2	0	4	3.8	
09 28 1964	15 41 00	44.0	96.4	0	0	3.4	
09 09 1966	09 50 31	41.4	98.6	0	0	3.5	
11 23 1967	06 23 39	43.7	99.4	0	5	3.8	
07 08 1968	16 50 12	46.5	100.6	25000	4	4.4	
10 19 1971	21 07 31	44.0	101.0	0	0	3.0	
10 16 1972	05 47 33	42.3	99.6	0	0	3.7	
05 13 1975	07 53 38	42.1	98.4	0	6	3.5	
07 09 1975	14 54 15	45.5	96.1	315000	6	4.8	

Table 4

SOURCE REGION NEMAHA RIDGE
AREA= 206071 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
04 24 1867	20 22 00	39.5	96.7	800000	7	5.3	
04 28 1867	00 00 00	40.7	95.8	0	4	3.8	
11 08 1875	10 40 00	39.3	95.5	22000	5	4.2	
12 09 1875	09 00 00	40.7	95.8	0	3	3.4	
11 15 1877	17 45 00	41.0	97.0	450000	7	5.3	
01 08 1906	00 15 00	39.3	96.6	95000	7- 8	5.5	
01 08 1906	00 38 00	39.3	96.6	0	0	3.0	
01 08 1906	04 30 00	39.3	96.6	0	0	3.0	
01 08 1906	07 00 00	39.3	96.6	0	2- 3	3.2	
01 08 1906	08 00 00	39.3	96.6	0	2- 3	3.2	
01 14 1906	15 00 00	39.3	96.6	0	2- 3	3.2	
01 16 1906	02 40 00	39.3	96.6	40000	4	3.8	
01 20 1906	05 30 00	39.3	96.6	0	3	3.4	
01 23 1906	13 40 00	39.3	96.6	0	3	3.4	
01 23 1906	14 25 00	39.3	96.6	0	3	3.4	
01 11 1907	07 45 00	37.1	97.0	0	4	3.8	
07 19 1908	00 00 00	35.7	97.7	0	3	3.4	
09 10 1918	16 30 00	35.5	98.0	1000	5- 6	4.5	
09 11 1918	06 30 00	35.5	97.9	1000	5- 6	4.5	
09 11 1918	09 00 00	35.5	97.9	0	2- 3	3.2	
00 00 1918	00 00 00	35.5	97.7	0	3- 4	3.6	
05 27 1919	03 06 00	37.7	97.3	25000	4	4.2	
07 26 1919	10 00 00	37.7	97.3	0	3	3.4	
07 26 1919	12 55 00	37.7	97.3	10000	4	3.8	
06 03 1924	00 40 00	36.3	96.5	0	3	3.4	
01 07 1927	09 30 00	38.3	97.7	10000	5	4.2	
09 23 1929	10 00 00	39.0	96.6	0	5	4.0	
09 23 1929	11 00 00	39.0	96.6	40000	5	4.2	
10 21 1929	21 30 00	39.2	96.5	20000	5	4.2	
10 23 1929	00 00 00	39.0	96.8	0	2- 3	3.2	
12 07 1929	09 02 00	39.2	96.6	2500	5	4.2	
12 28 1929	00 30 00	35.5	97.9	17000	6	4.7	
08 19 1933	19 30 00	35.5	96.0	500	6	4.7	
03 01 1935	10 59 44	40.3	96.2	210000	7	5.3	
03 01 1935	11 04 00	40.3	96.2	0	0	3.0	
03 22 1935	22 45 00	40.3	96.1	0	4	3.8	
06 08 1937	14 26 00	35.3	96.9	2500	4	3.8	
10 18 1941	07 48 00	35.4	99.0	250	5	4.2	
06 12 1942	04 50 00	36.4	97.9	4000	3	3.4	
04 03 1948	03 00 00	37.7	97.3	0	4	3.8	
04 09 1952	16 29 29	35.4	97.8	640000	7	5.5	
04 11 1952	18 30 00	35.4	97.8	0	2- 3	3.2	
04 11 1952	20 30 00	35.4	97.8	8000	4	3.8	
04 16 1952	05 58 00	35.4	97.8	8000	2- 3	3.2	
04 16 1952	06 05 00	35.4	97.8	8000	5	4.2	
07 17 1952	00 30 00	35.4	97.8	0	3- 4	3.6	
07 17 1952	02 00 00	35.4	97.8	0	3- 4	3.6	
08 14 1952	21 40 00	35.4	97.8	0	4	3.8	
03 16 1953	12 50 00	35.4	97.9	0	3	3.4	
03 17 1953	13 12 00	35.6	96.0	0	5	4.2	
03 17 1953	14 25 00	35.6	98.0	7000	6	4.7	

(Continued)

Table 4 (Concluded)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
01 06 1956	11 57 59	37.3	98.7	60000	6	4.7	
02 16 1956	23 30 00	35.4	97.3	13000	6	4.7	
06 17 1959	10 27 07	34.6	98.4	37000	6	4.7	
10 10 1965	23 51 33	36.1	97.7	0	0	3.1	
05 30 1969	14 08 05	34.8	97.8	0	0	3.0	
07 01 1969	03 36 58	37.4	97.0	0	0	3.0	
09 13 1975	01 25 03	34.1	97.4	0	4	3.8	

the panhandle of Texas. Earthquakes in this zone for which focal mechanisms solutions could be obtained have fault planes which strike along the direction of the mountain front. Table 5 lists the earthquakes associated with this zone.

22. The Wabash Valley seismic zone includes southeastern Illinois and western Indiana. Five earthquakes with m_b greater than or equal to 5 occurred within it in the last 100 years. Many of the earthquakes apparently are related to the approximately north-south trending Wabash valley fault zone. Table 6 contains the earthquakes of that region.

23. The Ozark Uplift zone includes the St. Francois highlands of southeast Missouri and the Illinois basin of southwestern Illinois. It also contains the Centralia, Illinois fault zone, near which there were several damaging earthquakes in the nineteenth century. Table 7 contains the earthquakes located in the Ozark Uplift zone.

24. The New Madrid seismic zone is by far the most active region of the central United States, even if one considers only the earthquakes which happened after 1812. For this report the zone is subdivided into regions A and B, the former being the central area with the higher rate of seismicity and linear microearthquake trends (Figure 1) and the latter the surrounding area. Table 8 and 9 list the earthquakes located in each of the two regions.

25. The Residual Events zone includes all of the central United States which does not lie in one of the previously described source

Table 5

SOURCE REGION WICHITA-OUACHITA
AREA= 261829 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
07 18 1894	00 00 00	35.0	90.0	0	3	3.4	
01 27 1898	01 35 00	34.6	90.6	0	4	3.8	
04 00 1907	00 00 00	35.5	101.2	0	0	3.0	
07 19 1908	00 00 00	35.7	97.7	0	3	3.4	
03 31 1911	16 57 00	33.8	92.2	50000	6	4.7	
03 31 1911	18 10 00	33.8	92.2	6500	4- 5	4.0	
10 08 1915	16 50 00	35.7	95.3	8000	3	3.4	
01 28 1917	00 00 00	35.4	101.3	0	2- 3	3.2	
03 24 1917	00 00 00	35.3	101.2	0	5	4.2	
03 27 1917	19 56 00	35.3	101.3	5000	6	4.7	
03 27 1917	23 38 00	35.3	101.3	0	0	3.0	
09 10 1918	16 30 00	35.5	98.0	1000	5- 6	4.5	
09 11 1918	06 30 00	35.5	97.9	1000	5- 6	4.5	
09 11 1918	09 00 00	35.5	97.9	0	2- 3	3.2	
10 04 1918	09 21 00	34.7	91.7	80000	5	4.4	
00 00 1918	00 00 00	35.5	97.7	0	3- 4	3.6	
07 30 1925	12 17 00	35.4	101.3	500000	6	4.8	
01 20 1926	00 00 00	35.6	94.9	47000	5	4.2	
06 20 1926	14 20 00	35.6	94.9	47000	5	4.2	
12 28 1929	00 30 00	35.5	97.9	17000	6	4.7	
10 16 1930	12 30 00	34.3	92.7	0	0	3.0	
11 16 1930	12 30 00	34.3	92.8	900	5	4.2	
08 19 1933	19 30 00	35.5	98.0	500	6	4.7	
04 11 1934	17 40 00	33.9	95.5	8000	5	4.2	
03 14 1936	17 20 00	34.0	95.2	2300	5	4.2	
06 20 1936	03 13 00	35.7	101.4	0	0	3.0	
06 20 1936	03 18 00	35.7	101.4	0	0	3.0	
06 20 1936	03 24 06	35.7	101.4	110000	6	4.7	
07 12 1936	00 23 00	36.9	102.9	500	3- 4	3.6	
06 08 1937	14 26 00	35.3	96.9	2500	4	3.8	
04 26 1938	05 42 00	34.2	93.5	0	4	3.8	
06 01 1939	07 30 00	35.0	96.4	65000	4	4.3	
06 19 1939	21 43 12	34.1	92.6	65000	5	4.3	
10 18 1941	07 48 00	35.4	99.0	250	5	4.2	
03 12 1948	04 29 00	36.0	102.5	300000	6	4.7	
06 20 1951	19 37 10	35.0	102.0	65000	6	4.7	
04 09 1952	16 29 29	35.4	97.8	640000	7	5.5	
04 11 1952	18 30 00	35.4	97.8	0	2- 3	3.2	
04 16 1952	20 30 00	35.4	97.8	8000	4	3.8	
04 16 1952	05 58 00	35.4	97.8	8000	2- 3	3.2	
04 16 1952	06 05 00	35.4	97.8	8000	5	4.2	
07 17 1952	00 30 00	35.4	97.8	0	3- 4	3.6	
07 17 1952	02 00 00	35.4	97.8	0	3- 4	3.6	
08 14 1952	21 40 00	35.4	97.8	0	4	3.8	
10 08 1952	04 15 00	35.1	96.5	0	4	3.8	
03 16 1953	12 50 00	35.4	97.9	0	3	3.4	
03 17 1953	13 12 00	35.6	98.0	0	5	4.2	
03 17 1953	14 25 00	35.6	98.0	7000	6	4.7	
06 06 1953	17 40 00	34.7	96.7	0	4	3.8	
04 11 1954	00 00 00	35.0	96.4	0	4	3.8	
04 12 1954	23 05 00	35.0	96.4	0	4	3.8	

(Continued)

Table 5 (Concluded)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
04 13 1954	18 48 00	35.1	96.4	0	4	3.8	
02 16 1956	23 30 00	35.4	97.3	13000	6	4.7	
04 02 1956	16 03 00	34.2	95.6	5000	5	4.2	
02 10 1959	20 05 00	35.5	100.9	120000	5	4.5	
06 15 1959	12 45 00	34.7	96.7	13000	5	4.2	
06 17 1959	10 27 07	34.6	98.4	37000	6	4.7	
05 04 1960	16 31 32	34.2	92.0	0	4	3.8	
01 11 1961	01 40 00	34.9	95.5	6500	5	4.2	
04 26 1961	07 05 00	34.6	95.0	6500	3	3.8	
04 27 1961	03 00 00	34.6	95.0	0	0	3.0	
04 27 1961	05 00 00	34.6	95.0	0	0	3.0	
04 27 1961	07 30 00	34.9	95.3	20000	5	4.2	
02 07 1963	21 18 36	34.4	92.1	0	0	3.4	
02 02 1964	08 23 00	35.1	99.7	0	5	4.2	
10 10 1965	23 51 33	36.1	97.7	0	0	3.1	
07 20 1966	09 04 59	35.6	101.4	30000	4- 5	3.8	
06 04 1967	16 14 14	33.6	90.9	54000	6	4.5	3.0
06 29 1967	13 57 07	33.6	90.9	0	5	4.0	
01 04 1968	00 00 00	34.9	95.5	0	4	3.8	
01 01 1969	23 35 36	34.8	92.6	62000	6	4.5	3.3
04 13 1969	06 27 51	34.2	96.3	0	0	3.5	
05 02 1969	11 33 20	35.2	96.3	0	5	4.0	
05 30 1969	14 08 05	34.8	97.8	0	0	3.0	
01 08 1973	09 11 37	33.8	90.6	0	3	3.5	
05 25 1973	14 40 14	33.9	90.8	0	3	3.4	
04 25 1973	14 42 32	33.9	90.8	0	0	3.2	
02 15 1974	13 33 49	36.5	100.7	0	5	4.6	
02 15 1974	22 32 35	33.9	93.1	0	3	3.6	
02 15 1974	22 35 45	34.0	93.1	0	3	3.6	
02 15 1974	22 49 02	34.0	93.0	0	5	4.0	
12 13 1974	05 03 58	34.7	91.9	0	5	3.4	
01 02 1975	09 19 00	34.9	90.9	0	2- 3	3.0	

Table 6

SOURCE REGION WABASH VALLEY
AREA= 39780 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA		IO	MB	MS
08 07 1860	15 30 00	37.8	87.5	60000		5	4.4	
03 26 1872	00 00 00	37.1	88.6	0		3	3.4	
09 25 1876	06 00 00	38.5	87.8	0		6	4.7	
09 25 1876	06 15 00	38.5	87.8	150000		6	4.7	
09 26 1876	00 00 00	38.5	87.8	0		3	3.4	
05 26 1877	21 00 00	38.2	87.9	0	3-	4	3.6	
01 10 1883	20 25 00	37.4	89.3	0		3	3.4	
02 06 1887	22 15 00	38.7	87.5	170000	5-	6	4.7	
07 27 1891	02 28 00	37.9	87.5	0		6	4.5	
04 30 1899	02 05 00	38.8	87.0	100000	6-	7	5.0	
09 21 1903	00 00 00	38.7	88.1	0		4	3.8	
05 11 1906	06 15 00	38.5	87.2	3200		4	3.8	
09 07 1906	16 33 00	38.2	87.7	1500		4	3.8	
01 30 1907	05 30 00	39.5	86.6	0		5	4.2	
09 27 1909	09 45 00	39.5	87.4	250000		7	5.3	
10 23 1909	09 47 00	39.0	87.8	35000		5	4.2	
02 05 1915	06 55 00	37.7	88.6	1000		4	3.8	
04 15 1915	13 20 00	38.7	88.1	8000	2-	3	3.8	
01 07 1916	19 45 00	39.1	87.0	8000		3	3.8	
02 18 1916	01 27 00	37.6	88.8	0		3	3.4	
02 11 1919	03 37 00	37.8	87.5	5000	3-	4	3.8	
05 25 1919	09 45 00	38.4	87.5	65000		5	4.4	
03 14 1921	12 15 00	39.5	87.5	65000		4	4.4	
03 31 1921	20 03 00	37.9	87.8	0		4	3.8	
10 01 1921	09 00 00	37.7	88.6	10000		4	4.0	
01 11 1922	03 42 00	37.9	87.8	25000	4-	5	4.2	
03 22 1922	22 30 00	37.3	88.9	150000		5	4.6	
03 23 1922	04 30 00	37.3	88.9	0		5	4.2	
11 27 1922	03 31 00	37.8	88.5	130000	6-	7	5.0	
04 02 1924	11 15 00	37.1	88.6	0		4	3.8	
04 27 1925	04 05 00	38.3	87.6	250000	6-	7	5.0	
09 02 1925	11 55 00	37.8	87.5	200000		6	4.8	
09 20 1925	09 00 00	37.8	87.5	25000		4	4.1	
03 22 1926	14 30 00	37.8	88.6	10000		4	4.0	
10 04 1926	04 20 00	38.3	87.6	0		3	3.4	
10 27 1926	04 20 00	38.3	87.6	10000		4	4.0	
01 14 1929	20 12 00	38.3	87.6	2500		4	3.8	
01 06 1931	04 51 00	39.0	87.0	1300		5	4.2	
04 01 1931	23 20 09	36.9	88.3	5000		3	3.8	
12 31 1931	00 00 00	38.5	87.2	0		2	3.0	
10 30 1934	02 25 47	37.5	88.5	4000		4	3.8	
05 31 1940	19 03 00	37.1	88.6	2500		5	4.2	
12 29 1940	04 30 00	37.9	87.3	1800		3	3.6	
03 29 1942	12 43 00	37.7	88.6	500		4	3.8	
03 26 1947	00 00 00	37.0	88.4	0		4	4.0	
08 09 1954	00 00 00	38.5	87.3	0		4	3.8	
04 11 1955	10 50 00	37.7	88.6	0		2	3.0	
05 30 1955	00 00 00	38.1	88.9	0		3	3.4	
03 26 1957	08 27 06	37.0	88.4	800		4	3.8	
11 08 1958	04 41 43	38.4	87.9	85000		6	4.7	
06 27 1962	01 28 56	37.7	88.5	45000		5	4.4	

(Continued)

Table 6 (Concluded)

DATE			OT(UT)			LAT	LON	FELT AREA	IO	MB	MS
06	22	1966	11	27	53	38.6	88.2	0	0	3.1	
11	09	1968	17	01	41	38.0	88.5	1600000	7	5.5	5.2
11	09	1968	17	08	17	38.0	88.5	0	4	3.8	
02	28	1969	13	10	13	37.9	88.9	0	0	3.2	
12	08	1970	23	16	00	38.0	89.0	0	0	3.0	
02	12	1971	12	44	27	38.5	87.9	10000	4	3.3	
04	03	1974	23	05	02	38.6	88.1	0	6	4.7	

Table 7

SOURCE REGION OZARK UPLIFT
AREA= 36557 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
09 02 1819	08 00 00	37.7	89.7	0	5	4.2	8.0
09 17 1819	04 00 00	38.1	89.8	0	4	3.8	8.0
09 17 1819	00 00 00	38.1	89.8	0	3- 4	3.6	8.0
06 09 1838	14 45 00	38.5	89.0	500000	7- 8	5.7	0.0
10 08 1857	10 00 00	38.7	89.2	200000	7	5.3	
07 24 1871	00 00 00	37.0	90.0	0	3	3.4	
07 25 1871	06 40 00	38.5	90.0	2500	3	3.6	
07 28 1882	00 00 00	37.6	90.6	25000	3- 4	4.1	
09 27 1882	10 20 00	39.0	89.5	100000	4	4.7	
10 15 1882	05 50 00	39.0	89.5	20000	5	4.2	
10 15 1882	10 35 00	39.0	89.5	20000	5	4.2	
10 22 1882	06 10 00	38.9	89.4	0	3	3.4	
12 05 1883	15 20 00	36.3	91.2	250000	5	4.2	
02 14 1884	12 00 00	37.7	90.7	0	3	3.4	
10 30 1895	14 30 00	36.4	90.6	0	3	3.4	
10 30 1895	20 00 00	36.4	90.6	0	3	3.4	
10 30 1895	22 30 00	36.4	90.6	0	3	3.4	
04 15 1898	03 20 00	36.4	90.6	0	0	3.0	
02 09 1903	00 21 00	37.8	89.3	180000	6	4.8	
20 05 1903	02 56 00	37.0	90.0	120000	5- 6	4.6	
11 03 1903	18 00 00	37.8	89.3	0	3- 4	3.6	
01 30 1907	00 00 00	38.9	89.5	3000	5	4.2	
07 04 1907	09 00 00	37.8	90.4	1000	4- 5	3.8	
08 16 1909	22 45 00	38.3	90.1	45000	4	4.3	
10 22 1909	22 00 00	37.6	90.6	0	4	3.8	
04 09 1917	20 52 00	38.1	90.2	550000	6	5.0	
04 09 1917	23 38 00	38.1	90.2	0	4	3.8	
05 08 1917	09 00 00	36.8	90.4	10000	3- 4	3.9	
05 08 1917	15 00 00	36.8	90.4	0	3	3.4	
06 09 1917	13 14 00	36.8	90.4	45000	4	4.3	
10 13 1918	09 30 00	36.1	91.0	4500	5	4.2	
04 08 1919	12 30 00	36.2	91.3	0	3- 4	3.6	
11 03 1919	20 40 00	36.3	91.0	0	4- 5	4.0	
04 30 1920	15 12 00	38.6	89.1	10000	4	4.0	
05 01 1920	15 15 00	38.5	89.5	60000	4- 5	4.3	
05 01 1920	16 09 00	38.5	89.5	0	0	3.0	
09 09 1921	03 00 00	38.3	90.1	10000	4	4.0	
09 09 1921	05 45 00	38.3	90.1	0	0	3.0	
10 09 1921	07 50 00	38.3	90.1	8000	3	3.8	
10 09 1921	11 50 00	38.3	90.1	0	3	3.4	
03 28 1922	16 42 00	36.7	90.4	6000	3	4.0	
03 09 1923	04 45 00	38.9	89.4	10000	3- 4	3.9	
02 01 1927	01 30 00	37.4	89.7	10000	4	4.0	
02 02 1927	08 00 00	36.7	90.4	8000	4	3.8	
11 10 1928	06 20 00	36.1	91.1	0	4	3.8	
12 26 1928	03 25 00	36.1	91.1	0	4	3.8	
02 26 1929	08 15 00	37.6	90.6	0	4	3.8	
01 26 1930	21 00 00	36.1	91.1	0	4	3.8	
02 25 1930	12 45 00	37.0	90.2	0	3- 4	3.6	
03 11 1933	12 48 00	36.7	90.4	0	4	3.8	
03 11 1933	13 04 00	36.7	90.4	0	4	3.8	

(Continued)

Table 7 (Concluded)

DATE	OT(UT)	LAT	LON	FELT AREA		IO	MB	MS
07 13 1933	14 42 39	37.9	89.9	0		3	3.4	
08 04 1933	04 34 15	37.9	89.9	1200		4	3.8	
04 17 1934	13 53 00	37.9	89.9	0		3	3.4	
05 15 1934	14 28 00	37.9	89.9	0	3-	4	3.6	
11 23 1936	09 38 40	36.6	90.6	0		2	3.0	
11 25 1936	17 42 35	36.6	90.6	0		2	3.0	
03 18 1937	11 58 00	37.7	89.9	0	2-	3	3.2	
11 17 1937	17 04 00	38.6	89.1	50000		5	4.4	
01 17 1938	04 18 00	37.7	89.9	0		3	3.4	
11 23 1939	15 14 53	38.2	90.1	400000		5	4.9	
11 15 1941	20 04 00	38.3	90.2	0		3	3.4	
01 07 1944	05 18 00	37.5	89.7	2300		4	3.8	
09 25 1944	11 37 23	37.9	90.0	65000		4	4.4	
01 16 1945	04 00 00	37.8	90.2	1800		4	3.8	
02 25 1946	00 52 00	38.6	89.1	4000		4	3.8	
05 15 1946	06 10 00	36.6	90.8	32000	3-	4	4.2	
10 08 1946	01 12 02	37.5	90.6	80000	4-	5	4.4	
12 01 1947	07 47 33	36.7	90.6	27000		4	4.2	
01 06 1948	01 34 00	38.6	89.1	600	4-	5	4.0	
06 08 1949	19 51 36	38.1	90.3	800		3	3.4	
12 30 1953	22 00 00	38.6	89.1	3000		4	3.8	
02 02 1954	16 53 00	36.7	90.3	80000		6	4.4	
04 09 1955	13 01 24	38.1	89.9	50000	5-	6	4.5	
11 26 1956	04 12 44	37.1	90.6	70000		6	4.7	
09 09 1961	22 43 02	36.4	91.3	0		4	3.8	
07 08 1963	23 51 43	37.0	90.5	0		0	3.1	
09 24 1964	08 09 34	37.1	91.1	0		0	3.0	
10 21 1965	02 04 38	37.5	91.0	420000		6	4.9	4.1
11 03 1965	12 33 22	37.1	91.1	0		0	3.0	
11 04 1965	07 43 39	37.1	91.1	0		0	3.5	
02 14 1966	00 08 56	37.2	90.9	0		0	3.1	
02 26 1966	08 10 20	37.2	91.0	0		0	3.7	
07 21 1967	09 14 49	37.5	90.4	53000		6	4.3	2.8
08 25 1967	19 15 18	37.1	91.1	0		0	3.1	
02 13 1966	23 19 37	37.1	91.0	0		4	3.6	
01 20 1969	19 25 00	37.8	90.4	0		3	3.4	
12 08 1970	23 16 00	38.0	89.0	0		0	3.0	
02 01 1972	05 42 10	36.4	90.8	27000	5-	6	4.2	2.8
06 09 1972	19 15 19	37.7	90.4	350	3-	4	3.1	
01 12 1973	11 56 56	37.9	90.5	0		4	3.2	
06 05 1974	08 06 11	38.6	89.9	0		5	3.6	
08 11 1974	14 29 45	36.9	91.2	0		5	3.6	

Table 8

SOURCE REGION NEW MADRID A
AREA= 22506 KM**2

DATE			OT(UT)			LAT	LON	FELT AREA	IO	MB	MS
12	16	1811	08	15	00	36.0	90.0	5000000	10-11	7.2	8.0
01	23	1812	15	00	00	36.3	89.6	5000000	10-11	7.1	7.8
02	07	1812	09	45	00	36.5	89.6	5000000	11-12	7.4	8.2
07	25	1816	15	00	00	36.5	89.5	0	3- 4	3.6	0.0
07	25	1816	21	00	00	36.5	89.5	0	3- 4	3.6	0.0
03	00	1818				36.2	89.7	0	3	3.4	
		1820				36.6	89.5	0	3- 4	3.6	
12	28	1841	05	50	00	36.6	89.2	0	5	4.2	0.0
05	28	1842	05	00	00	36.6	89.2	0	4	3.8	0.0
11	04	1842	06	30	00	36.6	89.2	0	5	4.2	
11	04	1842	08	30	00	36.6	89.2	0	5	4.2	
01	05	1843	02	45	00	35.5	90.5	1500000	8	6.0	
02	17	1843	05	00	00	35.5	90.5	250000	5	4.8	
06	13	1843	15	00	00	36.6	89.2	0	3	3.4	
03	26	1846	17	25	00	36.6	89.6	0	3	3.4	
01	24	1848	00	00	00	36.6	89.2	0	5	4.2	
08	28	1853	00	00	00	36.6	89.2	0	3	3.4	
12	12	1853	00	00	00	36.6	89.2	100000	4- 5	4.5	
11	09	1856	00	00	00	36.6	89.5	80000	4	4.4	
02	00	1857	00	00	00	36.6	89.5	0	4	3.8	
09	21	1858	00	00	00	36.5	89.2	0	6	4.7	
08	17	1865	15	00	00	36.5	89.5	250000	7	5.3	
09	07	1865	14	15	00	36.6	89.5	0	3 4	3.6	
11	21	1868	00	00	00	36.6	89.2	0	3	3.4	
12	14	1870	00	00	00	36.6	89.2	0	3- 4	3.6	
04	20	1872	07	00	00	35.1	90.0	0	3	3.4	
08	20	1872	00	00	00	35.1	90.0	0	2- 3	3.2	
05	03	1873	21	00	00	36.6	89.6	30000	4	4.2	
08	22	1873	19	00	00	35.1	90.0	0	2- 3	3.2	
10	07	1875	00	00	00	36.1	89.6	50000	3- 4	4.3	
10	28	1875	03	00	00	35.1	90.0	0	4	3.8	
07	15	1877	00	40	00	36.8	89.7	65000	3- 4	4.3	
03	12	1878	10	00	00	36.8	89.1	40000	5	4.2	
11	19	1878	05	52	00	36.7	89.3	350000	4	4.9	
09	26	1879	03	10	00	35.3	90.3	10000	3- 4	3.9	
07	14	1880	02	30	00	35.3	90.3	25000	4	4.1	
10	07	1881	16	52	00	35.1	90.0	0	4	3.8	
06	11	1883	18	16	00	35.1	90.0	0	4	4.7	
11	30	1884	05	00	00	35.5	89.7	12000	4	4.0	
11	03	1888	00	00	00	35.4	90.4	0	4	3.8	
06	06	1889	04	28	00	35.1	90.0	0	3	3.4	
07	20	1889	01	32	00	35.2	90.0	0	6	3.8	
01	14	1891	00	00	00	35.1	90.0	0	3- 4	3.6	
01	14	1892	09	05	00	35.1	90.0	0	3	3.4	
07	18	1894	00	00	00	35.0	90.0	0	3	3.4	
10	03	1895	00	00	00	35.2	90.0	0	3	3.4	
10	18	1895	03	00	00	36.6	89.5	0	3	3.4	
10	18	1895	06	10	00	36.6	89.5	0	3	3.4	
04	26	1897	04	00	00	35.8	89.6	20000	4- 5	4.1	
06	14	1898	15	20	00	36.0	89.4	120000	4	4.5	
02	15	1901	00	15	00	36.0	90.0	30000	4	4.2	

(Continued) (Sheet 1 of 5)

Table 8 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
09 14 1901	00 00 00	35.1	90.0	0	3	3.4	
11 04 1903	18 18 00	36.9	89.3	340000	7	5.3	
11 04 1903	19 14 00	36.9	89.3	0	6	4.7	
11 24 1903	15 20 00	36.6	89.5	0	3	3.4	
11 25 1903	00 00 00	36.6	89.5	0	2- 3	3.2	
11 27 1903	07 00 00	36.5	89.5	30000	5	4.2	
11 27 1903	09 20 00	36.5	89.5	180000	5	4.2	
08 22 1905	05 08 00	36.8	89.6	325000	6- 7	5.0	
09 28 1908	19 34 00	36.6	89.6	13000	4	4.0	
10 23 1909	07 10 00	37.0	89.5	125000	5- 6	4.6	
04 28 1915	23 40 00	36.5	89.5	500	4- 5	4.0	
12 07 1915	18 40 00	36.7	89.1	120000	5- 6	4.6	
05 21 1916	18 24 00	36.6	89.5	20000	4	4.1	
12 19 1916	05 42 00	36.6	89.2	0	5- 6	4.5	
05 23 1919	12 30 00	36.6	89.2	8000	3	3.9	
05 24 1919	13 30 00	36.6	89.2	8000	3	3.9	
05 26 1919	13 25 00	36.6	89.2	8000	3	3.8	
05 28 1919	11 30 00	36.6	89.2	8000	3	3.8	
05 28 1919	13 45 00	36.6	89.5	8000	3	3.8	
01 09 1921	21 54 00	36.4	89.5	5000	4	3.8	
03 30 1922	16 53 00	36.1	89.6	40000	4- 5	4.2	
10 28 1923	17 10 00	35.5	90.4	120000	7	5.3	
11 26 1923	23 25 00	35.5	90.4	23000	4	4.1	
01 01 1924	03 05 00	35.4	90.3	150000	5	4.6	
06 07 1924	05 42 00	36.4	89.5	25000	4- 5	4.2	
04 28 1926	04 16 00	36.2	89.6	10000	4	4.0	
12 13 1926	23 03 00	36.7	89.4	8000	3	3.8	
12 17 1926	00 00 00	36.4	89.5	10000	4	4.0	
04 18 1927	10 30 00	36.3	89.5	10000	4	4.0	
05 07 1927	08 28 00	35.7	90.6	300000	7	5.3	
08 13 1927	16 10 00	36.4	89.5	65000	5	4.4	
04 15 1928	11 00 00	36.6	89.5	0	4	3.8	
04 23 1928	11 00 00	36.5	89.2	0	4	3.8	
05 31 1928	22 40 00	36.6	89.5	0	4	3.8	
05 13 1929	03 50 00	36.4	89.5	5000	3	3.8	
01 02 1930	16 30 00	35.7	89.5	0	2	3.0	
02 18 1930	17 00 00	35.5	90.4	0	3	3.4	
03 26 1930	08 50 00	35.2	89.9	0	2- 3	3.2	
03 27 1930	08 56 00	35.1	90.1	1000	4	3.8	
04 02 1930	09 39 00	36.1	89.7	0	4	3.8	
08 13 1930	19 59 52	36.6	89.5	0	2	3.0	
09 01 1930	20 27 28	36.6	89.4	10000	5	4.2	
07 18 1931	14 52 00	36.6	89.5	5000	4	3.8	
12 10 1931	08 11 36	35.9	89.9	5000	4	3.8	
11 22 1931	07 56 42	36.0	90.2	2500	3	3.6	
12 09 1933	08 50 00	35.8	90.2	250	6	4.2	
07 02 1934	15 10 41	35.2	90.0	0	4	3.8	
07 03 1934	00 00 00	36.2	89.7	0	2	3.0	
07 24 1935	01 38 00	36.4	89.5	0	4	3.8	
02 17 1936	05 05 08	36.2	89.7	0	4	3.8	
08 02 1936	22 16 25	36.7	89.0	20000	3	3.8	

(Continued) (Sheet 2 of 5)

Table 8 (Continued)

DATE			OT(UT)			LAT	LON	FELT AREA		IO	MB	MS
10	20	1936	21	17	00	36.6	89.6	0		2	3.0	
10	31	1936	16	11	38	36.6	89.6	0		2	3.0	
01	30	1937	08	57	09	36.2	89.7	5000		4	3.8	
06	23	1937	15	28	00	36.4	89.5	0		3	3.4	
10	05	1937	22	58	00	36.6	89.5	0		3	3.4	
03	16	1938	10	12	00	36.6	89.6	0		2	3.0	
06	17	1938	00	00	00	35.8	89.9	0		3	3.4	
09	17	1938	01	57	00	35.5	90.3	0		0	3.0	
09	17	1938	03	34	24	35.5	90.3	250000	4-	5	4.8	
09	17	1938	07	20	00	35.5	90.3	0	2-	3	3.2	
09	28	1938	11	32	00	36.5	89.9	0		3	3.4	
04	15	1939	17	25	00	36.8	89.4	1000		3	3.4	
09	19	1939	00	00	00	36.4	89.5	0		3	3.4	
02	14	1940	11	10	00	35.9	89.8	0		3	3.4	
09	19	1940	23	43	00	36.5	89.6	0	2-	3	3.2	
10	10	1940	19	34	00	36.8	89.2	0	2-	3	3.2	
10	08	1941	07	51	00	36.2	89.7	3000	4-	5	4.0	
08	27	1941	03	59	00	36.7	89.7	0		3	3.4	
11	15	1941	03	07	00	35.1	90.0	0		4	3.8	
11	17	1941	03	08	00	35.5	89.7	50000		6	4.7	
11	30	1942	16	53	00	36.8	89.7	0		3	3.4	
12	23	1944	07	23	00	36.2	89.7	0		4	3.8	
05	02	1945	11	22	00	36.5	89.7	5000		4	3.8	
08	06	1945	23	52	00	36.1	89.7	0		3	3.4	
08	07	1945	04	05	00	36.1	89.7	0		3	3.4	
09	23	1945	06	22	00	36.0	89.8	0		4	3.8	
10	27	1945	10	42	00	36.5	89.5	0		3	3.4	
12	15	1947	03	27	00	35.6	90.1	15000		5	4.2	
01	14	1949	03	49	00	36.4	89.7	4000		5	4.2	
01	31	1949	00	00	00	36.3	89.7	4000		5	4.2	
08	13	1949	21	45	00	36.1	89.7	0		3	3.4	
05	01	1950	15	30	00	36.5	89.9	0	2-	3	3.2	
09	17	1950	05	48	00	35.7	89.9	0	3-	4	3.8	
12	18	1951	02	02	00	35.6	90.3	0		3	3.4	
12	18	1951	08	00	00	35.6	90.3	0	2-	3	3.2	
02	20	1952	22	34	39	36.4	89.5	34000		5	4.2	
03	17	1952	01	30	00	36.2	89.6	0		4	3.8	
05	28	1952	09	54	14	36.6	89.7	3000		4	3.8	
07	16	1952	23	48	10	36.2	89.6	0		6	4.7	
07	17	1952	00	09	00	36.2	89.6	0		4	3.8	
10	17	1952	04	16	00	36.2	89.6	1000		4	3.8	
10	17	1952	04	30	00	36.2	89.6	0	2-	3	3.2	
10	17	1952	04	35	00	36.2	89.6	0	2-	3	3.2	
10	17	1952	04	46	00	36.2	89.6	0	2-	3	3.2	
12	25	1952	04	23	24	35.9	89.8	23000		4	4.1	
12	25	1952	00	00	00	35.9	89.8	0		2	3.0	
12	28	1952	16	59	00	36.7	89.6	0		3	3.4	
01	26	1953	23	18	00	36.0	89.5	0		4	3.8	
01	27	1953	06	48	00	36.0	89.5	0		4	3.8	
01	27	1953	07	48	00	36.0	89.5	0		2	3.0	
02	11	1953	10	50	54	36.5	89.5	3000		4	3.8	

(Continued) (Sheet 3 of 5)

Table 8 (Continued)

DATE			OT(UT)			LAT	LON	FELT AREA	IO	MB	MS
02	17	1953	11	05	00	36.5	89.5	0	4	3.8	
02	18	1953	00	17	00	36.5	89.5	0	3	3.4	
02	19	1953	05	05	00	36.0	89.5	0	3	3.4	
05	12	1953	18	50	00	35.6	90.3	0	4	3.8	
01	17	1954	07	15	00	36.0	89.4	1000	4	3.8	
04	27	1954	04	09	00	35.1	90.0	40000	5	4.4	
01	25	1955	07	24	30	36.0	89.5	90000	6	4.7	
03	29	1955	09	03	00	36.0	89.5	10000	6	4.7	
09	06	1955	01	45	00	36.0	89.5	0	5	4.2	
09	06	1955	00	00	00	36.0	89.5	0	3	3.4	
09	24	1955	18	45	00	36.4	89.5	0	4	3.8	
12	13	1955	07	43	00	36.0	89.5	0	5	4.2	
12	13	1955	07	56	00	36.0	89.5	0	3	3.4	
01	24	1956	05	00	00	36.1	89.7	0	2- 3	3.2	
01	29	1956	04	44	15	35.6	89.6	13000	6	4.7	
10	29	1956	09	23	44	36.1	89.7	0	5	4.2	
08	17	1957	23	00	00	36.2	89.5	0	4	3.8	
01	26	1958	16	55	37	36.1	89.7	17000	5	4.2	
04	08	1958	22	25	33	36.3	89.2	2000	5	4.2	
04	26	1958	07	30	00	36.4	89.5	1800	4	4.2	
05	20	1958	01	25	00	35.5	90.4	0	4	3.8	
01	21	1959	15	35	00	36.3	89.5	0	4	3.8	
02	13	1959	08	37	00	36.1	89.5	450	5	4.2	
07	20	1959	08	15	26	35.9	89.8	0	3	3.4	
12	21	1959	16	25	00	36.0	89.5	1000	5	4.2	
01	28	1960	21	38	00	36.0	89.5	800	5	4.2	
04	21	1960	10	45	00	36.0	89.5	0	5	4.2	
02	02	1962	06	43	29	35.6	89.6	90000	6	4.3	3.5
06	01	1962	11	23	41	36.0	90.2	0	0	3.2	
07	23	1962	06	05	18	36.1	89.8	10000	6	4.2	
03	31	1963	13	31	04	36.9	89.5	0	0	3.0	
04	06	1963	08	12	24	36.4	89.8	0	0	3.1	
05	02	1963	01	09	22	36.7	89.4	0	0	3.1	
01	16	1964	05	09	57	36.8	89.5	0	0	3.2	
01	25	1964	19	54	10	36.5	89.5	0	0	3.0	
03	17	1964	02	16	06	36.2	89.6	0	0	3.5	
05	23	1964	11	25	34	36.5	89.9	0	0	3.9	
05	23	1964	15	00	35	36.5	90.0	0	0	3.6	
02	11	1965	03	40	24	36.4	89.7	0	3	3.3	
03	25	1965	12	59	28	36.4	89.5	0	0	3.7	
05	25	1965	07	15	43	36.1	89.9	0	0	3.3	
06	01	1965	07	24	57	36.5	89.5	0	0	3.0	
07	08	1965	07	03	50	36.5	89.5	0	0	3.3	
12	19	1965	22	19	10	35.9	89.9	0	0	3.6	
02	12	1966	04	32	15	35.9	90.0	2500	4	3.6	
03	13	1966	14	24	42	36.2	90.0	0	0	3.0	
04	11	1967	23	44	45	36.1	89.7	0	0	3.0	
07	06	1967	16	43	51	35.8	90.4	0	0	3.4	
10	18	1967	05	08	36	36.5	89.5	0	0	3.0	
01	23	1968	16	16	00	36.5	89.5	0	0	3.3	
02	10	1968	01	34	32	36.5	89.7	0	3	3.5	

(Continued) (Sheet 4 of 5)

Table 8 (Concluded)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
05 30 1968	01 59 33	36.5	89.5	0	0	3.5	
07 15 1968	04 21 25	36.5	89.5	0	0	3.0	
01 07 1970	17 45 00	35.2	89.9	0	4	3.8	
03 27 1970	03 44 29	36.5	89.7	0	3	3.3	
11 05 1970	10 25 35	36.0	90.0	0	0	3.0	
11 17 1970	02 13 55	35.9	90.1	92000	6	4.4	2.9
11 30 1970	04 46 53	36.3	89.5	10	3- 4	3.0	
12 14 1970	12 41 00	35.7	90.0	0	0	3.0	
12 24 1970	10 17 57	36.7	89.5	4000	4	3.6	
04 13 1971	14 00 51	35.8	90.1	0	0	3.0	
10 01 1971	18 49 39	35.8	90.4	62000	5- 6	4.1	2.9
10 18 1971	06 39 31	36.7	89.6	0	0	3.0	
03 29 1972	20 38 32	36.2	89.6	0	5	3.7	
05 07 1972	02 12 08	35.9	90.0	0	4	3.4	
10 03 1973	03 50 20	35.9	90.0	0	4	3.4	
10 09 1973	20 15 27	36.5	89.6	0	4	3.7	
12 20 1973	10 45 00	36.2	89.6	0	4	3.4	
01 08 1974	01 12 37	36.2	89.4	0	5	4.3	
02 24 1974	07 53 45	35.8	90.4	0	0	3.2	
03 04 1974	14 24 28	35.7	90.3	0	0	3.0	
03 12 1974	12 30 29	35.7	89.8	0	0	3.2	
05 13 1974	06 52 19	36.7	89.4	0	6	4.1	
02 13 1975	19 43 58	36.5	89.6	0	5	3.3	
06 13 1975	22 40 27	36.5	89.7	0	5	4.3	
08 25 1975	07 11 08	36.0	89.8	0	0	3.0	

(Sheet 5 of 5)

Table 9

SOURCE REGION NEW MADRID B
AREA= 27506 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
11 09 1820	22 00 00	37.3	89.5	0	5	4.2	0.0
09 05 1839	00 00 00	36.7	88.6	0	4	3.8	0.0
05 03 1855	03 33 00	37.0	89.2	0	4	3.8	
05 03 1855	10 00 00	37.0	89.2	0	3	3.4	
07 24 1871	00 00 00	37.0	90.0	0	3	3.4	
02 08 1872	11 00 00	37.0	89.2	0	3- 4	3.6	
07 09 1874	22 00 00	37.0	89.2	0	3- 4	3.6	
01 09 1878	04 30 00	37.0	89.2	0	3- 4	3.6	
07 26 1879	17 45 00	37.0	89.2	0	2- 3	3.4	
07 20 1882	10 00 00	36.9	89.2	0	5	4.2	
01 11 1883	07 12 00	37.0	89.2	200000	5- 6	4.6	
04 12 1883	08 30 00	37.0	89.2	0	6- 6	4.0	
07 06 1883	17 15 00	37.0	89.2	0	3	3.4	
07 14 1883	07 30 00	37.0	89.1	25000	4- 5	4.1	
03 18 1886	05 59 00	37.0	89.2	45000	4	4.7	
08 02 1887	18 36 00	37.0	89.2	170000	5	4.7	
09 27 1891	04 55 00	37.0	89.2	0	5	4.2	
10 31 1895	11 08 00	37.0	89.4	2500000	9	6.2	
11 02 1895	04 16 00	37.0	89.4	0	4	3.8	
11 02 1895	08 00 00	37.0	89.4	0	3- 4	3.6	
11 02 1895	17 00 00	37.0	89.4	0	3- 4	3.6	
11 17 1895	00 00 00	37.0	89.4	0	3- 4	3.6	
05 01 1897	04 00 00	37.0	89.0	0	4- 5	4.0	
20 05 1903	02 56 00	37.0	90.0	120000	5- 6	4.6	
10 28 1908	00 27 00	37.0	89.2	13000	4- 5	4.0	
12 27 1908	21 15 00	37.0	89.0	80000	4	4.4	
06 09 1913	15 30 00	35.8	88.9	10000	3	3.9	
02 19 1915	04 35 00	37.1	89.2	900	4	3.8	
10 26 1915	07 40 00	36.7	88.6	0	5	4.2	
08 24 1916	09 00 00	37.0	89.2	10000	4	3.8	
10 19 1916	08 00 00	36.7	88.6	0	3	3.4	
02 17 1918	08 10 00	37.0	89.2	8000	3	3.8	
05 07 1920	20 45 00	36.3	88.2	8000	2	3.8	
02 27 1921	22 16 00	37.0	89.2	8000	3	3.8	
03 23 1922	21 45 00	37.0	88.9	50000	4	4.3	
05 06 1923	07 50 00	37.0	89.2	10000	3- 4	3.9	
05 15 1923	23 42 00	37.0	89.2	8000	3- 4	3.8	
11 29 1923	23 20 00	37.0	89.2	0	4	3.8	
03 02 1924	11 18 00	37.0	89.1	80000	5	4.4	
05 13 1925	12 00 00	36.7	88.6	10000	4- 5	3.8	
04 15 1928	15 05 00	37.3	89.5	0	4	3.8	
08 29 1930	06 26 54	37.0	89.1	10000	4	4.0	
09 03 1930	12 00 00	37.0	88.9	0	3	3.4	
09 04 1930	05 30 00	37.0	88.9	0	3	3.4	
04 06 1931	15 37 03	36.8	89.0	1200	4	3.8	
10 24 1933	00 00 00	37.3	89.5	0	3	3.4	
08 20 1934	00 47 27	36.9	89.2	85000	6	4.7	
08 20 1934	03 37 25	37.0	89.2	0	2- 3	3.2	
12 20 1936	22 41 12	37.3	89.5	0	2	3.0	
05 17 1937	00 49 46	36.1	90.6	65000	4- 5	4.4	
02 04 1940	17 33 00	37.2	89.5	0	3	3.4	

(Continued)

Table 9 (Concluded)

DATE			OT(UT)			LAT	LON	FELT AREA	IO	MB	MS
10	21	1941	16	53	00	37.0	89.1	3000	4	3.8	
11	22	1941	21	55	00	37.3	89.5	0	2- 3	3.2	
08	31	1942	10	28	00	37.0	89.2	0	4	3.8	
11	13	1945	08	21	00	37.0	89.2	28000	4	4.1	
01	16	1947	16	23	00	37.0	89.2	0	2- 3	3.2	
05	06	1953	07	50	00	37.0	89.2	0	3	3.4	
05	15	1953	23	42	00	37.0	89.2	0	3	3.4	
02	02	1954	16	53	00	36.7	90.3	80000	6	4.4	
01	28	1958	05	56	40	37.1	89.2	40000	5	4.2	
07	14	1962	02	23	46	36.9	90.0	0	2- 3	3.2	
03	03	1963	17	30	11	36.7	90.0	280000	6	4.7	4.1
04	19	1963	14	31	55	36.7	90.1	0	0	3.5	
08	03	1963	00	37	50	37.0	88.8	6500	5	4.4	
08	14	1965	05	04	30	37.1	89.3	0	0	3.0	
08	14	1965	05	46	17	37.3	89.5	200	4	3.2	
08	14	1965	13	13	54	37.1	89.2	700	7	3.8	
08	15	1965	04	19	01	37.4	89.5	0	5	3.4	
08	15	1965	06	07	25	37.4	89.5	0	5	3.4	
06	19	1972	05	46	15	37.0	89.1	600	3	3.2	

regions. In general this area is described by a low density of earthquakes, most of which are of moderate to small magnitude. Table 10 lists the earthquakes in this region.

Focal Depth

26. For earthquakes whose focus lies in the earth's crust, there are in general three methods for determining focal depth. One makes use of the travel times of body waves recorded at points very near the epicenter. The second uses the travel-time differences between the direct P wave and a P wave that reflects off the earth's surface in the epicentral region. The third uses the excitation of long period Love and Rayleigh surface waves.

27. The density of distribution of seismographs in the central United States has been low. Consequently, it has not been possible to obtain the necessary data for precise focal depth determination using body waves recorded near the epicenter. The best that can be done with the existing data is to determine that the majority of earthquakes lie within the upper 20 km of the crust. Even in regions covered by microearthquake arrays, focal depths can be determined for only larger earthquakes.

28. The second method of determining focal depth can only be applied to earthquakes large enough to produce P waves that can be observed on seismographs at distances of 3000 km and greater.

Table 10

SOURCE REGION RESIDUAL EVENTS
AREA= 6185019 KM**2

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
04 11 1818	20 00 00	38.6	90.2	0	3- 4	3.6	0.0
05 30 1823	00 00 00	41.5	81.0	0	4	3.8	0.0
07 05 1827	11 30 00	38.3	85.8	430000	4	4.8	
08 07 1827	04 30 00	38.3	85.8	0	6	4.7	0.0
08 14 1827	00 00 00	38.6	90.2	0	3	3.4	0.0
03 10 1828	03 00 00	38.7	83.8	550000	5	4.8	0.0
05 00 1829	00 00 00	35.6	88.8	0	0	3.0	0.0
02 04 1833	00 00 00	42.3	85.6	20000	6	4.7	0.0
07 08 1836	00 00 00	41.5	81.7	0	4	3.8	0.0
02 14 1843	00 00 00	29.9	90.1	0	0	3.0	
08 09 1843	00 00 00	35.8	88.2	40000	3- 4	4.2	
11 28 1844	13 00 00	36.0	83.9	0	6	4.7	
04 05 1850	02 05 00	38.3	85.8	0	5	4.2	
10 01 1850	00 00 00	41.4	82.3	0	4	3.8	
02 12 1854	00 00 00	37.2	83.8	0	3- 4	3.6	
02 13 1854	00 00 00	37.2	83.8	0	3- 4	3.6	
02 28 1854	00 00 00	37.6	84.5	20000	4- 5	4.2	
03 08 1854	00 00 00	38.2	85.2	0	4	3.8	
03 01 1857	00 00 00	41.7	81.2	0	4- 5	4.0	
04 16 1858	12 00 00	41.7	81.3	0	4	3.8	
00 00 1860	00 00 00	46.0	94.8	0	6- 7	5.0	
01 13 1867	00 00 00	41.5	81.7	0	3	3.4	
02 20 1869	00 00 00	38.1	84.5	0	5	4.2	
04 09 1869	00 00 00	42.7	80.8	0	3	3.4	
02 06 1872	14 00 00	43.5	83.8	0	5	4.2	
07 09 1872	02 30 00	39.8	93.5	0	4	3.8	
07 23 1872	00 00 00	41.4	82.1	0	4	3.8	
05 01 1873	04 30 00	30.2	97.7	0	3- 4	3.6	
01 27 1876	00 00 00	41.9	84.0	0	0	3.0	
02 27 1876	00 00 00	42.4	83.2	0	0	3.0	
01 23 1877	21 00 00	38.8	83.5	2500	3	3.4	
06 03 1877	00 00 00	37.5	85.7	0	3	3.4	
08 17 1877	16 50 00	42.3	83.3	500	4- 5	4.0	
03 00 1879	00 00 00	39.6	99.1	0	4- 5	4.0	
11 30 1880	20 00 00	35.6	87.3	0	3	3.4	
12 28 1880	07 15 00	49.0	97.2	0	3- 4	3.6	
04 20 1881	00 00 00	41.6	85.8	0	4	3.8	
05 19 1881	15 00 00	38.9	95.2	0	3	3.4	
08 30 1881	05 00 00	39.2	83.7	0	3	3.4	
04 12 1882	05 00 00	29.9	90.1	0	3	3.4	
10 22 1882	22 15 00	33.6	95.6	500000	8	5.5	
11 16 1882	03 15 00	38.6	90.2	0	3	3.6	
02 04 1883	11 00 00	42.3	85.6	400000	4	4.7	
05 23 1883	04 30 00	38.4	82.6	0	4	3.8	
11 15 1883	03 14 00	38.7	90.2	0	4	3.8	
01 18 1885	11 30 00	41.3	81.1	0	3	3.4	
02 21 1885	00 00 00	37.2	94.3	0	3	3.4	
07 27 1885	00 00 00	35.2	88.2	0	3- 4	3.6	
08 15 1885	05 05 00	41.3	81.1	0	2- 2	3.2	
12 27 1885	01 05 00	40.4	89.0	0	3	3.4	
01 22 1886	16 38 00	30.4	92.0	0	0	3.0	

(Continued) (Sheet 1 of 8)

Table 10 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
03 01 1886	16 00 00	39.0	85.5	0	3- 4	3.6	
05 03 1886	03 00 00	39.5	92.1	1000	3- 4	3.6	
08 14 1886	00 00 00	39.7	96.1	0	3- 4	3.6	
06 06 1889	16 25 00	35.9	88.1	10000	3- 4	3.9	
01 08 1891	06 00 00	31.7	95.2	0	7	3.8	
07 27 1895	00 00 00	35.2	98.3	0	3- 4	3.6	
03 30 1898	01 30 00	36.8	85.8	0	3	3.4	
06 06 1898	08 30 00	37.7	84.3	0	3	3.4	
06 26 1898	08 30 00	37.7	84.3	0	3	3.4	
10 24 1898	00 00 00	41.5	81.7	0	3- 4	3.6	
02 09 1899	00 00 00	41.9	87.6	0	0	3.0	
10 11 1899	04 00 00	42.1	96.5	1700	4	3.8	
11 12 1899	14 00 00	39.3	83.0	0	4	3.8	
12 01 1899	18 50 00	36.8	94.4	0	4	3.8	
03 14 1900	03 00 00	45.5	89.5	0	3- 4	3.6	
03 14 1900	05 00 00	45.5	89.5	0	3- 4	3.6	
04 09 1900	14 00 00	41.4	81.8	0	6	4.7	
01 04 1901	03 12 00	37.8	94.0	5000	5	4.2	
05 17 1901	07 00 00	39.3	82.5	25000	5	4.2	
01 24 1902	10 48 00	38.6	90.2	130000	6	4.7	
03 10 1902	06 00 00	39.9	85.2	0	3- 4	3.6	
03 12 1902	11 30 00	39.9	85.2	0	3- 4	3.6	
05 29 1902	07 30 00	35.1	85.3	0	5	4.2	
06 14 1902	07 00 00	40.3	81.4	0	4- 5	4.0	
10 18 1902	22 00 00	35.0	85.3	0	5	4.2	
01 01 1903	18 30 00	39.9	85.2	0	2- 3	3.2	
01 01 1903	23 45 00	39.9	85.2	0	2- 3	3.2	
01 13 1903	14 53 00	38.8	95.3	0	2	3.0	
03 17 1903	11 50 00	39.1	89.5	0	3- 4	3.6	
09 20 1903	00 00 00	39.4	86.3	0	4	3.8	
11 20 1903	00 00 00	39.4	86.3	0	3	3.4	
12 11 1903	00 00 00	39.1	88.5	0	2	3.0	
10 28 1904	00 00 00	37.5	100.2	7000	5	4.2	
03 13 1905	16 30 00	45.1	87.7	0	5	3.8	
04 13 1905	16 30 00	40.4	91.6	13000	4- 5	4.0	
07 27 1905	00 20 00	47.3	88.4	40000	7	5.0	
08 22 1905	10 45 00	39.9	91.4	0	2- 3	3.2	
02 24 1906	05 15 00	39.7	92.3	0	3	3.4	
03 06 1906	00 00 00	39.7	91.4	0	4	3.8	
04 20 1906	18 30 00	41.5	81.7	0	4	3.8	
04 22 1906	00 00 00	43.0	87.9	0	0	3.0	
05 08 1906	06 58 00	39.5	85.8	6000	3- 4	3.6	
05 09 1906	06 38 00	39.2	85.9	0	4	3.8	
05 19 1906	09 20 00	42.9	85.7	0	0	3.0	
05 21 1906	19 00 00	38.7	88.4	0	5	4.3	
06 27 1906	12 10 00	40.4	81.6	1000	5	4.2	
08 08 1906	00 00 00	47.3	88.4	30000	0	3.8	
08 13 1906	13 19 00	39.7	86.8	0	4	3.8	
11 09 1906	00 00 00	47.1	98.6	0	0	3.0	
11 24 1906	05 15 00	39.7	92.3	0	3	3.4	
04 12 1907	00 00 00	41.5	81.7	0	3	3.0	

(Continued) (Sheet 2 of 8)

Table 10 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
12 11 1907	04 32 00	38.6	90.2	0	4	3.8	
11 12 1908	00 00 00	38.7	93.2	1800	4	3.8	
01 23 1909	03 15 00	47.2	88.6	0	5	3.4	
07 19 1909	04 34 00	40.2	90.0	100000	7	5.3	
09 22 1909	00 00 00	38.7	86.5	10000	5	4.2	
10 22 1909	00 00 00	38.9	84.5	0	0	3.0	
05 08 1910	17 30 00	30.1	96.0	0	4	3.8	
05 12 1910	00 00 00	30.1	96.0	2500	4	3.8	
02 28 1911	09 00 00	38.7	90.3	0	4	3.8	
07 29 1911	00 00 00	41.8	87.6	0	4- 5	3.2	
03 28 1913	21 50 00	36.2	83.7	7000	7	5.3	
11 11 1913	14 00 00	38.2	85.8	0	4	3.8	
01 24 1914	03 24 00	35.6	84.5	0	5	4.2	
10 07 1914	21 00 00	43.1	89.4	0	4	3.8	
12 30 1914	01 00 00	30.5	95.9	0	4- 5	3.5	
03 03 1915	07 45 00	47.3	88.4	0	3- 4	3.6	
08 08 1915	15 15 00	46.1	103.6	0	4	3.8	
10 04 1915	14 02 00	47.3	88.4	0	4- 5	4.0	
05 31 1916	22 45 00	43.1	89.3	0	2	3.0	
01 25 1917	22 15 00	35.9	86.8	0	2- 3	3.2	
01 26 1917	13 15 00	35.9	86.8	0	2- 3	3.2	
01 27 1917	21 00 00	35.9	86.8	0	2- 3	3.2	
02 06 1917	17 26 00	47.9	95.0	0	4	3.8	
09 03 1917	21 30 00	46.3	94.8	48000	6	4.7	
01 16 1918	15 45 00	35.9	83.9	0	5	4.2	
02 22 1918	00 00 00	42.8	84.2	0	4	3.8	
06 22 1918	01 00 00	36.1	84.1	8000	5	4.2	
07 01 1918	19 02 00	39.7	91.4	0	4	3.8	
10 01 1918	07 38 00	47.3	88.4	0	3	3.4	
10 16 1918	02 15 00	35.2	89.2	100000	5	4.5	
02 29 1920	03 05 00	37.2	93.3	60000	4	4.3	
10 03 1920	14 15 00	38.6	94.3	8000	3	3.8	
12 24 1920	07 30 00	36.0	85.0	0	5	4.2	
09 02 1921	14 00 00	36.2	86.3	0	3	3.4	
09 21 1921	00 00 00	36.0	86.1	0	3	3.4	
12 15 1921	13 20 00	35.8	84.6	0	5	4.2	
03 16 1922	09 30 00	43.0	82.5	0	3	3.4	
03 30 1922	04 20 00	35.5	86.7	0	4	3.8	
04 11 1922	05 00 00	40.9	90.6	0	2	3.0	
07 07 1922	00 00 00	43.8	88.5	0	5	4.2	
03 07 1923	05 03 00	31.7	106.5	50000	4- 5	4.3	
03 27 1923	08 00 00	34.6	89.7	10000	3- 4	3.9	
11 10 1923	04 00 00	40.0	89.9	1600	5	4.2	
11 28 1923	12 30 00	37.5	87.3	0	3	3.4	
09 24 1924	11 00 00	40.9	100.1	0	4	3.8	
01 26 1925	08 34 00	42.5	92.4	500	2	3.2	
01 27 1925	22 42 00	36.2	91.7	6000	3	3.8	
03 03 1925	16 00 00	42.1	87.7	0	2- 3	3.2	
04 04 1925	00 00 00	39.1	84.5	0	0	3.0	
07 08 1925	16 00 00	36.2	93.2	10000	4	3.8	
07 13 1925	00 00 00	38.8	90.0	0	5	4.2	

(Continued) (Sheet 3 of 8)

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Table 10 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
07 29 1925	11 30 00	34.5	101.2	0	4	3.8	
07 30 1925	08 00 00	34.5	100.3	0	5	4.2	
03 10 1926	00 00 00	36.8	101.7	0	0	3.0	
10 28 1926	08 42 00	41.7	83.6	0	3	3.4	
10 28 1926	11 00 00	41.7	83.6	0	4	3.8	
11 05 1926	15 53 00	39.1	82.1	900	6- 7	4.0	
01 16 1927	12 00 00	34.7	86.0	6500	5	4.2	
01 17 1927	05 30 00	40.7	82.5	0	4	3.8	
02 17 1927	06 00 00	40.7	82.5	0	2	3.0	
03 18 1927	17 25 00	39.9	95.3	800	5	4.2	
06 16 1927	12 00 00	34.7	86.0	6500	5	4.2	
07 20 1927	00 00 00	35.8	86.0	180000	6	4.7	
10 08 1927	12 56 00	35.0	85.3	0	5	4.2	
10 29 1927	00 00 00	40.9	81.2	0	5	4.2	
11 13 1927	16 21 00	32.3	90.2	8000	4	4.2	
12 15 1927	04 30 00	28.9	89.4	10000	4	4.2	
03 07 1928	02 45 00	35.6	87.0	5000	2- 3	3.4	
03 17 1928	21 15 00	38.6	90.2	1200	2	3.3	
09 09 1928	21 00 00	41.5	82.0	4000	5	4.2	
11 08 1928	14 15 00	39.5	89.1	0	4	3.8	
12 23 1928	06 10 00	47.6	93.9	0	4	3.8	
06 10 1929	00 00 00	41.5	81.7	0	3	3.4	
07 28 1929	17 00 00	28.9	89.4	8000	4	3.8	
09 17 1929	19 19 00	41.5	81.5	0	3	3.0	
11 27 1929	04 20 00	37.2	99.8	0	4	3.8	
01 24 1930	03 45 00	46.5	84.4	0	3	3.4	
05 28 1930	17 30 00	39.7	91.4	0	3	3.4	
08 08 1930	18 31 00	39.7	91.4	0	4	3.8	
08 30 1930	09 28 00	35.9	84.4	0	0	3.0	
10 16 1930	00 00 00	36.0	83.9	0	5	4.2	
10 19 1930	12 12 00	30.1	91.0	50000	6	4.7	
11 20 1930	00 00 00	42.6	83.4	0	3	3.4	
12 23 1930	14 44 00	38.5	90.7	2500	4	3.8	
08 09 1931	06 18 37	39.1	94.7	600	4- 5	4.0	
08 09 1931	07 07 00	39.1	94.7	0	0	3.0	
08 09 1931	07 15 00	39.1	94.7	0	0	3.0	
08 16 1931	11 40 21	30.6	104.1	1400000	8	5.6	
08 16 1931	19 33 00	30.6	104.1	0	0	3.0	
08 19 1931	02 36 00	30.6	104.1	0	6	0.	
08 19 1931	02 36 00	30.6	104.1	0	5	4.2	
08 26 1931	00 00 00	30.6	104.1	0	3	3.4	
10 02 1931	00 00 00	31.7	106.5	0	2- 3	3.2	
10 18 1931	21 12 00	43.1	89.4	0	3	3.4	
11 03 1931	15 50 00	29.9	104.2	0	2	3.2	
11 27 1931	09 23 00	36.2	86.8	0	3	3.4	
12 17 1931	03 36 00	34.1	89.9	220000	6- 7	5.0	
12 17 1931	21 08 19	38.6	90.2	0	2	3.0	
01 22 1932	00 00 00	41.1	81.5	0	5	4.2	
01 29 1932	00 15 00	39.0	99.6	5000	5	4.2	
04 09 1932	10 15 00	31.5	96.0	2500	5- 6	4.0	
01 29 1932	11 00 00	46.4	85.5	0	2	3.0	

(Continued) (Sheet 4 of 8)

Table 10 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
02 20 1933	17 00 00	39.8	99.9	15000	5	4.2	
05 28 1933	15 10 00	38.6	83.7	1600	5	4.2	
11 16 1933	09 29 01	38.6	90.6	4000	4	3.8	
01 30 1935	22 00 00	40.5	94.0	0	3	3.4	
02 26 1935	14 15 00	40.8	91.1	0	3	3.4	
05 26 1935	00 00 00	41.3	81.3	0	4	3.8	
10 00 1935	17 15 00	46.5	87.6	0	2- 3	3.2	
10 29 1935	00 00 00	39.6	90.8	0	0	3.0	
08 08 1936	01 40 00	31.7	106.5	0	3	3.4	
10 08 1936	16 30 00	39.3	84.4	1800	3	3.4	
10 15 1936	17 50 00	31.7	106.5	0	4	3.8	
12 26 1936	01 15 00	39.1	84.5	0	3	3.4	
12 26 1936	02 05 00	39.1	84.5	0	3	3.4	
03 30 1937	22 45 00	31.7	106.4	0	3	3.4	
06 29 1937	21 45 00	40.7	89.6	0	2	3.0	
08 05 1937	23 12 00	38.7	90.1	0	3	3.4	
08 08 1937	01 40 00	31.7	106.5	0	3	3.4	
10 17 1937	04 25 00	39.1	84.5	0	3	3.4	
02 12 1938	06 27 00	41.6	87.0	17000	5	4.2	
03 13 1938	16 10 00	42.4	83.2	0	4	3.8	
01 28 1939	17 55 00	46.8	95.8	20000	4	3.8	
06 24 1938	09 00 00	34.7	86.6	0	0	3.0	
06 24 1939	10 27 00	34.7	86.6	1300	4	3.8	
06 24 1939	11 45 00	34.7	86.6	0	0	3.0	
07 18 1939	00 00 00	45.7	87.1	0	0	3.0	
08 01 1939	00 00 00	45.7	87.1	0	0	3.0	
11 07 1939	10 00 00	45.7	87.1	0	2- 3	3.2	
01 08 1940	20 05 00	38.3	85.8	0	3	3.4	
05 27 1940	08 30 00	38.2	85.8	0	2- 3	3.2	
05 31 1940	17 00 00	41.1	81.5	0	2	3.0	
06 16 1940	04 30 00	40.9	82.3	0	4	3.8	
07 28 1940	09 30 00	40.9	82.3	0	3	3.4	
08 15 1940	10 35 00	40.9	82.3	0	3	3.4	
08 20 1940	03 30 00	40.9	82.3	0	3	3.4	
12 02 1940	16 16 00	33.0	94.0	0	4	3.8	
03 04 1941	00 00 00	36.0	83.9	0	2- 3	3.2	
06 28 1941	18 30 00	32.3	90.8	0	3- 4	3.6	
09 08 1941	09 45 00	35.0	85.3	250	4	3.8	
01 14 1942	18 05 00	38.4	90.3	1500	3	3.4	
01 23 1942	16 00 00	38.6	90.4	0	2	3.0	
01 29 1942	22 12 00	38.3	90.4	0	0	3.0	
01 30 1942	15 00 00	38.7	90.3	0	0	3.0	
09 10 1942	09 00 00	38.8	99.3	0	4	3.8	
11 17 1942	18 18 00	36.6	90.2	500	4	3.8	
11 18 1942	00 10 00	36.6	90.2	0	0	3.0	
12 27 1942	20 40 00	38.6	90.3	0	2- 3	3.2	
02 09 1943	23 21 00	45.2	88.2	0	2- 3	3.2	
02 15 1943	12 00 00	45.7	87.1	0	0	3.0	
03 09 1943	03 25 24	42.2	80.9	220000	5	4.7	
04 13 1943	17 00 00	36.3	85.8	0	4	3.8	
04 18 1943	08 36 00	38.3	85.8	0	4	3.8	

(Continued) (Sheet 5 of 8)

Table 10 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
05 20 1943	20 05 00	38.9	90.2	0	2	3.0	
05 24 1943	20 33 00	38.9	90.2	0	2	3.0	
06 08 1943	19 50 00	36.6	90.4	0	3- 4	3.6	
07 25 1943	06 49 10	36.1	91.3	0	4- 5	4.0	
11 16 1944	19 35 00	45.7	87.1	0	2- 3	3.2	
12 10 1944	11 00 00	45.7	87.1	0	4	3.8	
03 28 1945	01 45 58	38.6	90.2	8000	3	3.4	
05 18 1945	14 26 00	45.7	87.1	0	2	3.0	
05 21 1945	07 51 00	36.6	90.2	0	4	3.8	
04 06 1946	00 00 00	35.2	84.9	0	4	3.8	
10 26 1946	20 37 00	48.1	103.6	0	4	3.8	
11 07 1946	20 43 20	36.0	90.7	0	2- 3	3.2	
05 06 1947	21 27 00	43.0	87.9	8000	4- 5	4.0	
06 30 1947	04 23 53	38.4	90.2	40000	6	4.7	
08 10 1947	01 46 48	42.0	85.0	180000	6	4.7	
09 20 1947	21 30 00	31.9	92.6	0	4- 5	4.0	
01 15 1948	17 40 00	43.1	89.7	0	4	3.9	
01 18 1948	00 00 00	41.7	83.6	0	3	3.4	
02 09 1948	00 00 00	36.4	84.1	0	3	3.4	
02 10 1948	00 04 00	36.4	84.1	0	5- 6	4.5	
04 20 1948	14 17 00	41.7	91.8	0	4	3.8	
08 11 1949	16 32 00	36.6	90.3	0	2- 3	3.2	
08 26 1949	00 00 00	38.6	90.7	0	3	3.4	
02 08 1950	10 37 00	37.7	92.7	14000	5	4.2	
02 15 1950	10 05 00	46.1	95.2	3000	4- 5	4.0	
03 20 1950	13 24 00	33.5	97.1	0	4	3.8	
06 18 1950	00 00 00	35.8	84.0	0	4	3.8	
09 20 1951	02 38 00	38.7	89.9	3000	4	3.8	
12 03 1951	08 02 00	41.6	81.4	250	4	3.8	
12 07 1951	00 00 00	41.6	81.4	0	2	3.0	
12 22 1951	04 00 00	41.6	81.4	0	2	3.0	
01 07 1952	22 21 00	40.2	88.5	0	3	3.4	
06 20 1952	09 38 06	39.7	82.1	13000	6	4.7	
10 17 1952	15 48 00	30.1	93.7	0	4	3.8	
12 25 1952	00 00 00	43.8	81.0	0	4	3.8	
05 05 1953	00 00 00	39.8	82.1	0	4	3.8	
05 07 1953	23 32 00	39.7	82.1	0	4	3.8	
06 12 1953	00 00 00	41.7	83.6	0	4	3.8	
09 11 1953	18 26 28	38.8	90.1	15000	3	4.7	
11 10 1953	15 45 00	36.0	83.9	0	4	3.8	
12 31 1953	00 00 00	37.3	83.2	0	4	3.8	
01 02 1954	03 23 00	36.6	83.7	0	6	4.7	
01 05 1955	20 00 00	47.3	88.4	0	4	3.8	
01 05 1955	21 00 00	47.3	88.4	0	4	3.8	
01 07 1955	05 00 00	47.1	88.6	0	5	4.2	
01 07 1955	06 00 00	47.1	88.6	0	5	4.2	
01 12 1955	06 25 00	35.8	84.0	0	4	3.8	
01 25 1955	20 34 00	36.0	83.9	0	4	3.8	
01 27 1955	00 37 00	30.6	104.5	0	4	3.8	
02 01 1955	14 45 00	30.4	89.1	0	5	4.2	
05 26 1955	18 09 00	41.5	81.7	0	5	3.8	

(Continued) (Sheet 6 of 8)

Table 10 (Continued)

DATE	OT(UT)	LAT	LON	FELT AREA	IO	MB	MS
06 29 1955	01 16 00	41.5	81.7	0	5	3.8	
01 08 1956	00 35 00	29.3	94.8	0	4	3.8	
03 13 1956	15 15 00	40.5	90.4	5000	4	3.8	
07 18 1956	21 30 00	43.6	87.7	0	4	3.8	
07 18 1956	23 00 00	43.6	87.7	0	4	3.8	
09 09 1956	22 45 00	35.8	86.7	400	4	3.8	
10 13 1956	00 00 00	42.9	87.9	0	4	3.8	
10 30 1956	10 36 00	36.2	95.9	25000	7	4.7	
01 08 1957	16 00 00	43.5	88.8	0	3- 4	3.6	
01 25 1957	18 15 00	36.6	83.7	0	6	4.0	
03 19 1957	16 38 00	32.6	94.7	47000	5	4.3	
03 19 1957	17 41 00	32.6	94.7	0	0	3.0	
03 19 1957	22 36 00	32.6	94.7	0	0	3.0	
03 19 1957	22 45 00	32.6	94.7	0	0	3.0	
06 23 1957	06 34 18	36.5	84.5	0	5	4.2	
06 29 1957	00 00 00	42.9	81.3	0	4	3.8	
07 23 1957	13 03 00	38.7	83.8	0	3	3.4	
05 01 1958	22 47 00	41.5	81.7	0	4- 5	4.0	
10 23 1958	02 29 47	37.5	82.5	0	0	3.0	
11 06 1958	23 08 00	29.9	90.1	0	4	3.8	
11 19 1958	18 15 00	30.5	91.2	800	5	4.2	
01 06 1959	15 07 00	38.7	90.3	0	3	3.4	
06 13 1959	01 00 00	35.4	84.3	0	4	3.8	
08 12 1959	18 06 07	35.0	87.0	7000	6	4.7	
10 15 1959	15 45 00	29.8	93.1	6500	4	3.8	
04 15 1960	10 10 10	35.8	84.0	3400	5	4.2	
04 13 1961	21 14 57	39.9	100.0	3600	5	4.2	
12 25 1961	12 20 03	39.1	94.6	0	4	3.6	
12 25 1961	12 58 21	39.1	94.6	40000	5	3.8	
12 05 1963	06 51 02	37.2	87.0	0	2- 3	3.2	
12 15 1963	05 32 00	37.2	87.1	0	3	3.4	
02 18 1964	09 31 10	34.8	85.5	0	5	4.2	
04 24 1964	01 24 55	31.5	93.8	0	4	3.8	
04 24 1964	07 33 53	31.6	93.8	0	4	4.0	
04 24 1964	07 47 18	31.3	93.8	0	0	3.3	
04 24 1964	12 07 07	31.3	93.8	0	0	3.2	
04 24 1964	12 54 17	31.3	93.8	0	0	3.0	
04 26 1964	03 24 50	31.3	93.8	0	0	3.3	
04 27 1964	21 50 27	31.3	93.8	0	0	3.2	
04 28 1964	00 24 07	31.5	93.8	0	0	3.1	
04 28 1964	00 30 46	31.5	93.8	600	4	4.0	
04 28 1964	21 18 35	31.2	93.9	0	5	4.0	
04 30 1964	21 30 00	31.2	94.0	0	0	3.0	
05 02 1964	06 34 54	31.3	93.8	0	0	3.2	
05 03 1964	03 24 12	31.3	93.8	0	0	3.0	
05 07 1964	20 01 39	31.2	94.0	0	6	3.2	
06 03 1964	02 27 24	31.5	93.9	0	4	3.1	
06 03 1964	09 37 00	31.0	94.0	0	3- 4	3.6	
07 28 1964	00 00 00	36.0	83.9	0	2	3.0	
08 16 1964	11 35 31	31.4	93.8	0	5	3.0	
10 10 1964	08 30 00	47.4	89.8	0	0	3.0	

(Continued) (Sheet 7 of 8)

Table 10 (Concluded)

DATE			OT(UT)			LAT	LON	FELT AREA		IO	MB	MS
10	10	1964	11	30	00	47.3	90.3	0		0	3.0	
10	13	1964	16	30	00	36.0	83.9	0	2-	3	3.2	
02	14	1965	20	03	20	36.9	93.3	0		0	3.0	
03	06	1965	21	08	50	37.4	91.1	0		3	4.1	
08	30	1965	05	17	38	32.1	102.3	0		4	3.5	
12	09	1965	22	04	51	37.4	91.1	0		0	3.5	
03	24	1966	23	45	00	30.0	94.0	0		0	3.0	
06	26	1966	11	59	44	44.3	104.3	3000		6	3.1	
08	14	1966	15	25	52	31.7	103.1	50000		6	4.3	
08	24	1966	00	00	00	35.8	84.0	0		4	3.8	
09	28	1966	00	00	00	39.3	80.3	0		4	3.8	
12	06	1966	08	00	47	38.9	92.8	0		0	3.0	
02	02	1967	06	30	00	42.7	84.6	0		4	3.8	
04	08	1967	05	40	32	39.6	82.5	10000		5	4.2	
10	14	1968	14	42	54	34.0	96.8	0		6	3.5	
10	31	1968	00	00	00	43.0	83.0	0	3-	4	3.6	
12	11	1968	16	00	00	38.3	85.8	0		5	3.0	
07	13	1969	21	51	09	36.1	83.7	50000		5	4.3	
07	14	1969	11	15	00	36.0	83.9	0		2	3.0	
07	24	1969	18	10	00	36.0	83.9	0		3	3.4	
11	20	1969	01	00	09	37.4	81.0	250000		6	4.7	
02	03	1970	00	00	00	31.0	97.0	0		4	3.8	
02	06	1970	04	22	00	37.9	90.6	0		2	3.0	
02	06	1970	04	28	00	37.9	90.6	0		2	3.2	
02	06	1970	04	53	02	37.9	90.6	0		2	3.4	
07	06	1970	09	39	11	37.9	90.6	0		2	3.0	
07	30	1970	08	48	51	37.0	82.2	0		0	3.0	
08	11	1970	06	14	25	36.4	82.3	0		4	3.8	
02	19	1971	23	11	42	37.1	83.2	0		0	3.0	
03	14	1971	17	27	51	33.1	87.9	0		0	3.9	
03	15	1971	14	53	22	32.8	88.3	0		0	3.5	
03	16	1971	02	37	28	32.8	86.3	0		0	3.7	
03	17	1971	05	04	29	33.1	88.1	0		0	3.0	
04	01	1971	05	05	11	37.4	81.6	0		0	3.0	
07	30	1971	01	45	51	31.7	103.1	0		3	3.0	
07	31	1971	14	53	49	31.7	103.1	0		4	3.4	
01	09	1972	23	24	29	37.4	81.6	0		0	3.0	
05	20	1972	19	39	06	37.0	82.2	0		0	3.0	
01	07	1973	22	56	01	37.4	87.3	0		0	3.2	
10	30	1973	22	58	39	35.7	83.9	0		5	3.4	
11	30	1973	07	48	41	35.8	84.0	0		6	4.6	
06	05	1974	00	16	40	36.6	84.8	0		6	3.6	
10	20	1974	15	13	55	39.1	81.6	0		5	3.4	
02	16	1975	23	21	31	39.0	82.4	0		0	3.3	
03	01	1975	11	50	00	33.5	88.0	0		2	3.2	
06	24	1975	11	11	36	33.7	87.8	0		4	4.5	

(Sheet 8 of 8)

Practically this means that the earthquake must have a body-wave magnitude of about 5 or greater, which limits the applicability of the method to only a few central United States earthquakes.

29. The third method makes use of the fact that the period of the minimum in the spectrum of the Rayleigh-wave motion is a function of focal depth and of focal mechanism. Knowing the latter, one can find the former. Herrmann[13] applied this technique to sixteen earthquakes in the central United States. The shallowest, an August, 1965 Illinois event, had a depth of only 1.5 km. The deepest, which also occurred in Illinois in November 1968, had a depth of 22 km. Seventy-five percent of the earthquakes studied had depths between 5 and 16 km. His study supports the conclusion, based on the observation of travel times of body waves at small epicentral distances, that the foci of central United States earthquakes generally lie in the upper twenty kilometers of the crust.

Frequency Content of Seismic Waves

30. Damaging ground motion generally is confined to the frequency range of 1 to 10 Hz, which corresponds to the natural or resonant frequencies of most man-made structures. Until the mid-1970's all of the seismographs operating in the central United States had natural frequencies of approximately 1 Hz or less, so they did not respond to the higher-frequency part of the damaging ground-motion spectrum. Thus there was little information on the amount of high-

frequency source motion or on its dissipation with increasing epicentral distance.

31. Since the mid-1970's strong-motion accelerographs and microearthquake-recording seismographs have been operating in the New Madrid seismic zone. The strong-motion instruments were triggered by three earthquakes: the 13 June 1975 event in southeast Missouri, the 25 March 1976 event of eastern Arkansas and an aftershock of the latter earthquake. The strong-motion records showed that 10-Hz waves could be observed as far away as 150 km[14]. Seismograms from the microearthquake array shown in Figure 1 showed 10-Hz waves as distant as 370 km for other earthquakes[15]. Thus both sets of data indicate that excitation of 10-Hz wave energy occurs and that attenuation is relatively low for 10-Hz waves in the central Mississippi valley.

Focal Mechanisms

32. Herrmann[13] determined focal mechanisms for all the central United States earthquakes for which adequate data are available. He used the amplitude and phase spectra of long-period Rayleigh and Love waves and the P-wave first-motion data to infer the orientation of the fault plane, the type of faulting and the orientation of the pressure axes in those cases for which they were nearly horizontal. Twelve of the earthquakes were primarily of the strike-slip type. Two, in the St. Francois highlands of the Ozark uplift, indicated normal faulting.

One at the Ouachita mountain front in Arkansas and one in the Wabash valley of Illinois indicated reverse faulting. The pressure axes trended NE or E for most of the earthquakes having horizontal axes.

33. Herrmann and Canas[16] found that the fault planes of three earthquakes occurring along the southwest branch of the New Madrid fault zone had the same strike as the 120-km trend of microearthquakes along this branch of the fault zone. They also found that a fault-plane solution obtained from a composite of P-wave motions from a number of microearthquakes along the fault gave a similar focal mechanism, which indicated oblique faulting with a component of right-lateral strike-slip faulting as well as some vertical movement.

34. Knowledge of the focal mechanism, as well as the focal depth, is important if one wishes to compute synthetic seismograms or time histories of the ground motion at a particular site. In the central United States this capability at present exists only for the southwest branch of the New Madrid fault zone. This is the zone, however, which is capable of producing the largest earthquakes in the central and eastern United States. About 75 percent of the earthquakes studied by Herrmann[13] had significant components of strike-slip motion, which means that the earthquakes generate a substantial amount of tangential SH ground motion. The possibility exists for making theoretical estimates for other regions as well, though not as precisely as for earthquakes in the New Madrid seismic zone.

Attenuation

35. Attenuation of ground motion results from two principal causes: the geometrical spreading of energy as the distance increases and a frictional or absorptive loss. The latter is referred to as anelastic attenuation.

36. Geometric attenuation is in general independent of wave frequency or wavelength. Anelastic attenuation varies with wave frequency, being greater for the higher frequency waves. Anelastic attenuation also varies with crustal geology for wave frequencies of interest in earthquake engineering. In the United States, for example, the absorption of 1 to 10 Hz waves is greater in the western than in the eastern United States.

37. Nuttli and Dwyer[15] showed that the value of the specific dissipation factor, Q, for 1- to 10-Hz surface waves in the central United States is 1500. This corresponds to a coefficient of absorption of 0.0006 km^{-1} for 1-Hz waves and 0.006 km^{-1} for 10-Hz waves. Chouet et al[17] found an average Q value of 200 for tectonic provinces, such as California and Japan. This corresponds to a coefficient of absorption of 0.0045 km^{-1} for 1-Hz waves and 0.045 km^{-1} for 10-Hz waves.

Ground-Motion Character

38. Differences in attenuation of seismic waves in the central and western United States lead to differences in the character of the ground motion, depending on the epicentral distance. They affect the amplitude, the frequency and the duration of the ground motion.

39. At very small distances, out to 10 km, there will be no essential difference in the character of the ground motion, because absorption is not important at such distances. At distances of 10 to 100 km, 1-Hz waves will have essentially the same amplitude and duration in the central and western United States for earthquakes of similar magnitude. But 10-Hz waves in the West will be ten times smaller at 100 km distance than in the central region. Thus a time history in the central region will be richer in the high frequencies than one in the western region, but the 1-Hz waves will be essentially the same.

40. At distances of greater than 100 km the 10-Hz wave motion rarely is seen in the West, whereas it will be observable in the central region. The amplitudes of 1-Hz waves in the West will be comparable to those of 10-Hz waves in the central United States. In the latter region, the 1-Hz waves will maintain relatively large amplitudes, and will be especially noticeable in long and tall structures (ten stories and greater).

41. In general, one can conclude that within the near-field region of earthquakes the time history of central and western United States earthquakes will be practically the same. But in the far-field region the amplitude and acceleration will be greater in the central United States than in the West. Duration will be greater also in the central region, but the difference will not be so large as for amplitudes and accelerations.

42. These observations of the attenuation of seismic energy indicate that the transmission medium in the central region can potentially propagate destructive ground motion to larger distances than in the western region. Such would be the case if the energetics of the seismic sources in the two regions are the same. Estimation of the source spectra of earthquakes by Street *et al.*,[18] Street and Turcotte[19] for eastern North America and by Chouet *et al.*,[17] and Thatcher and Hanks[20] in the Western United States indicate substantial regional differences. In general, central United States earthquakes excite fewer higher frequencies than do western earthquakes for magnitudes less than 6.0. Larger eastern North American earthquakes seem to behave in the same manner as large earthquakes worldwide. This indicates that for design earthquakes having magnitudes, m_b, less than 6.0 in the central region, the effects of efficient high frequency wave propagation may be mitigated by low excitation of those frequencies.

PART IV: REGIONAL IDENTIFICATION OF CREDIBLE EARTHQUAKES

Methodology for Estimating Maximum-Magnitude Earthquakes

43. To specify the credible earthquake motion it is necessary to determine the maximum-magnitude earthquake for each seismic source region. Thus it is necessary to develop a methodology for determining the maximum-magnitude earthquake. In the central United States, where the location and extent of active faults are at best poorly known, one must rely principally on seismological rather than on geological data. The best available information is the catalog of earthquake activity. The problem is to find a procedure for estimating the maximum-magnitude earthquake from the data of the catalog.

44. There are two regions in the central and eastern United States where the maximum-magnitude earthquake can be presumed to have occurred in historic times. The first is the New Madrid region, where an earthquake of $m_b = 7.5$ occurred on 7 February 1812[2]. The second is the Charleston, South Carolina region, where an earthquake of $m_b = 6.6$ to 6.9 occurred on 31 August 1886[2]. A methodology is sought, then, which will give such magnitudes if these earthquakes are deleted from the catalog.

45. Figure 4 gives the cumulative magnitude-recurrence data and curve for New Madrid regions A and B, excluding the three major earthquakes of 1811-1812. The ordinate is the number of earthquakes

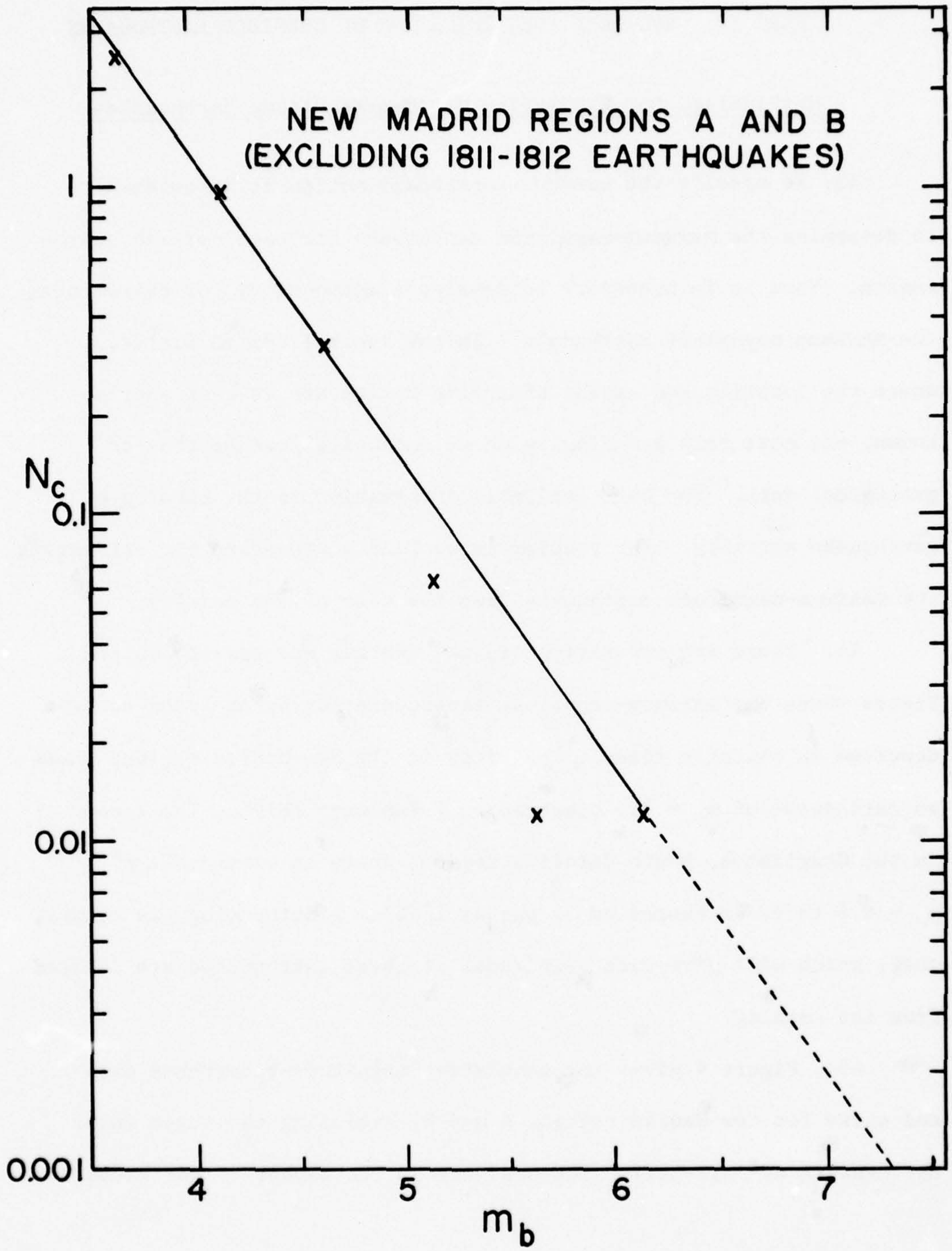

Figure 4. Cumulative magnitude-recurrence curve for New Madrid regions A and B, excluding the 1811-1812 earthquakes

per year equalling or exceeding the m_b value, which is the abscissa. For the smaller magnitudes the data of Tables 8 and 9 were examined for completeness, and the value of the number of earthquakes per year was derived only from the more recent years where the reporting of small-magnitude events is better than for the earlier years. The straight-line curve has a slope of 0.92, similar to that found by Nuttli[4] for a 140-year set of data for the central Mississippi valley. If the curve is extrapolated to N_c=0.001 (a recurrence period of 1000 years) the corresponding m_b is 7.35, which is very close to the presumed maximum magnitude of 7.5 for the region.

46. Figure 5 shows the cumulative magnitude-recurrence data and curve for the Charleston, South Carolina region, excluding the 1886 earthquake. The data, which are taken from Tarr[21], are fitted by a straight line of slope 0.70. The extrapolation to N_c=0.001 indicates an earthquake with a recurrence period of 1000 years will have an m_b of 6.85. This is within the range of values 6.6 to 6.9 assigned to the maximum-magnitude earthquake[2].

47. The procedure, then, to estimate the maximum-magnitude earthquake for a seismic source region will be to extrapolate the recurrence curve to obtain the m_b associated with a 1000-year recurrence period. Because the data for the other source regions of the central United States will not cover as large a magnitude interval as for New Madrid or Charleston, the slope will not be so well defined, which will lead to large uncertainties in estimating the maximum-magnitude

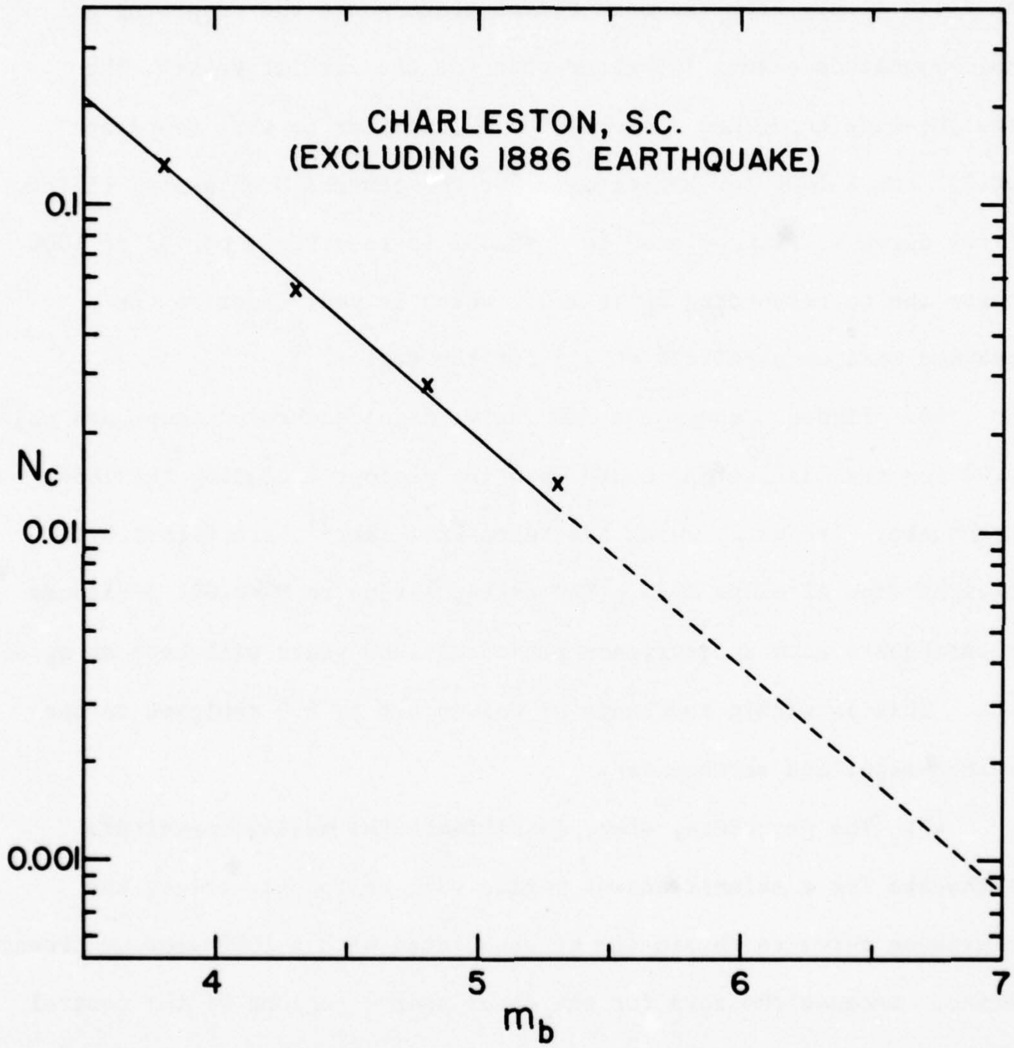

Figure 5. Cumulative magnitude-recurrence curve for the Charleston, South Carolina region, excluding the 1886 earthquake

earthquake. To avoid this problem the slope, for all central United States source regions, will be assumed to be 0.92, the value found for the central Mississippi valley[4]. The data will be fitted by the best straight line, in the sense of lease squares, which has a slope of 0.92. In this curve fitting procedure, the largest magnitude data point will be given one-half the weight of the other points.

48. The procedure described in paragraphs 45-47 does not take account of the area of the seismic source region. This is a shortcoming, for it is obvious that if the source area is enlarged there will be more earthquakes included in it and the magnitude-recurrence curve will be displaced upward, which would imply an increase in the value of the maximum-magnitude earthquake. To avoid this paradox the value of N_c must be equalized to a particular source area. The problem is to find the value of the source area to be used for equalization. If the New Madrid region is enlarged to include the entire central Mississippi valley, the apparent maximum-magnitude earthquake has a value larger than 7.5. To bring it back to 7.5, it is found that it is necessary to equalize to a source area of 100,000 km^2. That is, all the value of N_c must be divided by the ratio of the actual area to 100,000 km^2. This equalized value of N_c will be called N_c'.

49. Although the data of source regions with areas larger than 100,000 km^2 must be equalized, it does not follow that a similar procedure should be used for data from areas of less than 100,000 km^2.

That is, a small source region will have a small fault length, which will limit the size of the maximum-magnitude earthquake. To enlarge the area to 100,000 km^2 would hypothetically enlarge the length of the fault zone, and thus make the maximum-magnitude estimate too large. Therefore, the recurrence data are not equalized for area if the source region has an area of less than 100,000 km^2.

Recurrence Equations and Maximum-Magnitude Earthquakes for Central United States Source Regions

50. For the central United States the magnitude-recurrence equation is assumed to have the form

$$\log_{10} N_c' = a - 0.92\ m_b$$

where N_c' is the cumulative number of earthquakes of m_b or greater which occur in a 100,000 km^2 area in one year. If the source area is less than 100,000 km^2, N_c is the number of earthquakes of m_b or greater which occur in the source region in one year.

51. If the value of <u>a</u> in the magnitude-recurrence equation is determined for a particular source region, the value of the maximum-magnitude earthquake, $m_{b,max}$, can be found by putting $N_c' = 0.001$. Thus, by specifying the slope of the magnitude-recurrence curve, $m_{b,max}$ becomes a linear function of the intercept <u>a</u>.

52. Tables 11 through 20 present the ten-year activity rates and the cumulative activity rates per decade for each of the seismic source

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Table 11

TEN YEAR ACTIVITY RATES

SOURCE REGION ANNA,OHIO
AREA = 37605 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	2	0	0	0	0	0	0	0	0	0	2
1956-65	0	0	1	0	0	0	0	0	0	0	1
1946-55	0	1	1	0	0	0	0	0	0	0	2
1936-45	2	6	2	0	2	0	0	0	0	0	12
1926-35	1	11	2	0	2	0	0	0	0	0	16
1916-25	0	1	1	0	0	0	0	0	0	0	2
1906-15	0	1	0	0	0	0	0	0	0	0	1
1896 -5	0	0	1	0	0	0	0	0	0	0	1
1886-95	0	2	0	0	0	0	0	0	0	0	2
1876-85	1	1	1	1	0	0	0	0	0	0	4
1866-75	0	1	1	0	1	0	0	0	0	0	3
1856-65	0	0	0	0	0	0	0	0	0	0	0
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	1	0	0	0	0	0	0	0	0	0	1
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	0	0	0	0	0	0	0	0	0
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	7	24	10	1	5	0	0	0	0	0	47

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	2.00	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956-75	1.00	0.	0.50	0.	0.	0.	0.	0.	0.	0.
1946-75	0.67	0.33	0.67	0.	0.	0.	0.	0.	0.	0.
1936-75	1.00	1.75	1.00	0.	0.50	0.	0.	0.	0.	0.
1926-75	1.00	3.60	1.20	0.	0.80	0.	0.	0.	0.	0.
1916-75	0.83	3.17	1.17	0.	0.67	0.	0.	0.	0.	0.
1906-75	0.71	2.86	1.00	0.	0.57	0.	0.	0.	0.	0.
1896-75	0.63	2.50	1.00	0.	0.50	0.	0.	0.	0.	0.
1886-75	0.56	2.44	0.89	0.	0.44	0.	0.	0.	0.	0.
1876-75	0.60	2.30	0.90	0.10	0.40	0.	0.	0.	0.	0.
1866-75	0.55	2.18	0.91	0.09	0.45	0.	0.	0.	0.	0.
1856-75	0.50	2.00	0.83	0.08	0.42	0.	0.	0.	0.	0.
1846-75	0.46	1.85	0.77	0.08	0.38	0.	0.	0.	0.	0.
1836-75	0.50	1.71	0.71	0.07	0.36	0.	0.	0.	0.	0.
1826-75	0.47	1.60	0.67	0.07	0.33	0.	0.	0.	0.	0.
1816-75	0.44	1.50	0.63	0.06	0.31	0.	0.	0.	0.	0.
1806-75	0.41	1.41	0.59	0.06	0.29	0.	0.	0.	0.	0.

Table 12

TEN YEAR ACTIVITY RATES

SOURCE REGION NORTHERN ILLINOIS
AREA = 55128 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	0	0	0	1	0	0	0	0	0	0	1
1956-65	0	0	0	0	0	0	0	0	0	0	0
1946-55	0	1	0	0	0	0	0	0	0	0	1
1936-45	4	1	1	0	0	0	0	0	0	0	6
1926-35	0	2	2	1	0	0	0	0	0	0	5
1916-25	0	0	0	0	0	0	0	0	0	0	0
1906-15	0	4	1	1	1	0	0	0	0	0	7
1896 -5	0	0	0	0	0	0	0	0	0	0	0
1886-95	0	0	0	0	0	0	0	0	0	0	0
1876-85	0	0	0	1	0	0	0	0	0	0	1
1866-75	0	0	0	0	0	0	0	0	0	0	0
1856-65	0	0	0	0	0	0	0	0	0	0	0
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	0	0	0	0	0	0	0	0	0	0	0
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	0	0	0	0	0	0	0	0	0
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	4	8	4	4	1	0	0	0	0	0	21

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	0.	0.	0.	1.00	0.	0.	0.	0.	0.	0.
1956-75	0.	0.	0.	0.50	0.	0.	0.	0.	0.	0.
1946-75	0.	0.33	0.	0.33	0.	0.	0.	0.	0.	0.
1936-75	1.00	0.50	0.25	0.25	0.	0.	0.	0.	0.	0.
1926-75	0.80	0.80	0.60	0.40	0.	0.	0.	0.	0.	0.
1916-75	0.67	0.67	0.50	0.33	0.	0.	0.	0.	0.	0.
1906-75	0.57	1.14	0.57	0.43	0.14	0.	0.	0.	0.	0.
1896-75	0.50	1.00	0.50	0.38	0.13	0.	0.	0.	0.	0.
1886-75	0.44	0.89	0.44	0.33	0.11	0.	0.	0.	0.	0.
1876-75	0.40	0.80	0.40	0.40	0.10	0.	0.	0.	0.	0.
1866-75	0.36	0.73	0.36	0.36	0.09	0.	0.	0.	0.	0.
1856-75	0.33	0.67	0.33	0.33	0.08	0.	0.	0.	0.	0.
1846-75	0.31	0.62	0.31	0.31	0.08	0.	0.	0.	0.	0.
1836-75	0.29	0.57	0.29	0.29	0.07	0.	0.	0.	0.	0.
1826-75	0.27	0.53	0.27	0.27	0.07	0.	0.	0.	0.	0.
1816-75	0.25	0.50	0.25	0.25	0.06	0.	0.	0.	0.	0.
1806-75	0.24	0.47	0.24	0.24	0.06	0.	0.	0.	0.	0.

Table 13

TEN YEAR ACTIVITY RATES

SOURCE REGION NEMAHA RIDGE
AREA = 206071 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	2	1	0	0	0	0	0	0	0	0	3
1956-65	1	0	0	1	0	0	0	0	0	0	2
1946-55	2	6	2	3	0	1	0	0	0	0	14
1936-45	0	2	1	0	0	0	0	0	0	0	3
1926-35	2	1	5	2	1	0	0	0	0	0	11
1916-25	1	4	1	2	0	0	0	0	0	0	8
1906-15	0	2	0	0	0	0	0	0	0	0	2
1896 -5	5	4	0	0	0	1	0	0	0	0	10
1886-95	0	0	0	0	0	0	0	0	0	0	0
1876-85	0	0	0	0	1	0	0	0	0	0	1
1866-75	0	2	1	0	1	0	0	0	0	0	4
1856-65	0	0	0	0	0	0	0	0	0	0	0
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	0	0	0	0	0	0	0	0	0	0	0
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	0	0	0	0	0	0	0	0	0
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	13	22	10	8	3	2	0	0	0	0	58

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	2.00	1.00	0.	0.	0.	0.	0.	0.	0.	0.
1956-75	1.50	0.50	0.	0.50	0.	0.	0.	0.	0.	0.
1946-75	1.67	2.33	0.67	1.33	0.	0.33	0.	0.	0.	0.
1936-75	1.25	2.25	0.75	1.00	0.	0.25	0.	0.	0.	0.
1926-75	1.40	2.00	1.60	1.20	0.20	0.20	0.	0.	0.	0.
1916-75	1.33	2.33	1.50	1.33	0.17	0.17	0.	0.	0.	0.
1906-75	1.14	2.29	1.29	1.14	0.14	0.14	0.	0.	0.	0.
1896-75	1.63	2.50	1.13	1.00	0.13	0.25	0.	0.	0.	0.
1886-75	1.44	2.22	1.00	0.89	0.11	0.22	0.	0.	0.	0.
1876-75	1.30	2.00	0.90	0.80	0.20	0.20	0.	0.	0.	0.
1866-75	1.18	2.00	0.91	0.73	0.27	0.18	0.	0.	0.	0.
1856-75	1.08	1.83	0.83	0.67	0.25	0.17	0.	0.	0.	0.
1846-75	1.00	1.69	0.77	0.62	0.23	0.15	0.	0.	0.	0.
1836-75	0.93	1.57	0.71	0.57	0.21	0.14	0.	0.	0.	0.
1826-75	0.87	1.47	0.67	0.53	0.20	0.13	0.	0.	0.	0.
1816-75	0.81	1.38	0.63	0.50	0.19	0.13	0.	0.	0.	0.
1806-75	0.76	1.29	0.59	0.47	0.18	0.12	0.	0.	0.	0.

Table 14

TEN YEAR ACTIVITY RATES

SOURCE REGION NORTHERN GREAT PLAINS
AREA = 426723 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	1	3	0	2	0	0	0	0	0	0	6
1956-65	1	6	1	2	0	0	0	0	0	0	10
1946-55	1	11	0	0	0	0	0	0	0	0	12
1936-45	0	6	4	1	0	0	0	0	0	0	11
1926-35	1	7	4	1	0	0	0	0	0	0	13
1916-25	0	6	0	1	0	0	0	0	0	0	7
1906-15	1	3	3	1	0	0	0	0	0	0	8
1896 -5	0	3	0	2	0	0	0	0	0	0	5
1886-95	0	1	2	0	0	0	0	0	0	0	3
1876-85	0	1	1	0	1	0	0	0	0	0	3
1866-75	0	2	1	0	0	0	0	0	0	0	3
1856-65	0	0	0	0	0	0	0	0	0	0	0
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	0	0	0	0	0	0	0	0	0	0	0
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	0	0	0	0	0	0	0	0	0
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	5	49	16	10	1	0	0	0	0	0	81

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	1.00	3.00	0.	2.00	0.	0.	0.	0.	0.	0.
1956-75	1.00	4.50	0.50	2.00	0.	0.	0.	0.	0.	0.
1946-75	1.00	6.67	0.33	1.33	0.	0.	0.	0.	0.	0.
1936-75	0.75	6.50	1.25	1.25	0.	0.	0.	0.	0.	0.
1926-75	0.80	6.60	1.80	1.20	0.	0.	0.	0.	0.	0.
1916-75	0.67	6.50	1.50	1.17	0.	0.	0.	0.	0.	0.
1906-75	0.71	6.00	1.71	1.14	0.	0.	0.	0.	0.	0.
1896-75	0.63	5.63	1.50	1.25	0.	0.	0.	0.	0.	0.
1886-75	0.56	5.11	1.56	1.11	0.	0.	0.	0.	0.	0.
1876-75	0.50	4.70	1.50	1.00	0.10	0.	0.	0.	0.	0.
1866-75	0.45	4.45	1.45	0.91	0.09	0.	0.	0.	0.	0.
1856-75	0.42	4.08	1.33	0.83	0.08	0.	0.	0.	0.	0.
1846-75	0.38	3.77	1.23	0.77	0.08	0.	0.	0.	0.	0.
1836-75	0.36	3.50	1.14	0.71	0.07	0.	0.	0.	0.	0.
1826-75	0.33	3.27	1.07	0.67	0.07	0.	0.	0.	0.	0.
1816-75	0.31	3.06	1.00	0.63	0.06	0.	0.	0.	0.	0.
1806-75	0.29	2.88	0.94	0.59	0.06	0.	0.	0.	0.	0.

Table 15

TEN YEAR ACTIVITY RATES

SOURCE REGION WICHITA-OUACHITA
AREA = 261829 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	3	7	3	3	0	0	0	0	0	0	16
1956-65	3	4	4	2	0	0	0	0	0	0	13
1946-55	2	10	3	4	0	1	0	0	0	0	20
1936-45	0	2	3	0	0	0	0	0	0	0	5
1926-35	3	1	3	3	0	0	0	0	0	0	10
1916-25	3	1	3	5	0	0	0	0	0	0	12
1906-15	1	2	1	1	0	0	0	0	0	0	5
1896 -5	0	1	0	0	0	0	0	0	0	0	1
1886-95	0	1	0	0	0	0	0	0	0	0	1
1876-85	0	0	0	0	0	0	0	0	0	0	0
1866-75	0	0	0	0	0	0	0	0	0	0	0
1856-65	0	0	0	0	0	0	0	0	0	0	0
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	0	0	0	0	0	0	0	0	0	0	0
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	0	0	0	0	0	0	0	0	0
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	15	29	20	18	0	1	0	0	0	0	83

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	3.00	7.00	3.00	3.00	0.	0.	0.	0.	0.	0.
1956-75	3.00	5.50	3.50	2.50	0.	0.	0.	0.	0.	0.
1946-75	2.67	7.00	3.33	3.00	0.	0.33	0.	0.	0.	0.
1936-75	2.00	5.75	3.25	2.25	0.	0.25	0.	0.	0.	0.
1926-75	2.20	4.80	3.20	2.40	0.	0.20	0.	0.	0.	0.
1916-75	2.33	4.17	3.17	2.83	0.	0.17	0.	0.	0.	0.
1906-75	2.14	3.86	2.86	2.57	0.	0.14	0.	0.	0.	0.
1896-75	1.88	3.50	2.50	2.25	0.	0.13	0.	0.	0.	0.
1886-75	1.67	3.22	2.22	2.00	0.	0.11	0.	0.	0.	0.
1876-75	1.50	2.90	2.00	1.80	0.	0.10	0.	0.	0.	0.
1866-75	1.36	2.64	1.82	1.64	0.	0.09	0.	0.	0.	0.
1856-75	1.25	2.42	1.67	1.50	0.	0.08	0.	0.	0.	0.
1846-75	1.15	2.23	1.54	1.38	0.	0.08	0.	0.	0.	0.
1836-75	1.07	2.07	1.43	1.29	0.	0.07	0.	0.	0.	0.
1826-75	1.00	1.93	1.33	1.20	0.	0.07	0.	0.	0.	0.
1816-75	0.94	1.81	1.25	1.13	0.	0.06	0.	0.	0.	0.
1806-75	0.88	1.71	1.18	1.06	0.	0.06	0.	0.	0.	0.

Table 16

TEN YEAR ACTIVITY RATES

SOURCE REGION WABASH VALLEY
AREA = 39780 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	3	1	0	1	0	1	0	0	0	0	6
1956-65	1	1	0	2	0	0	0	0	0	0	4
1946-55	1	2	1	0	0	0	0	0	0	0	4
1936-45	0	2	1	0	0	0	0	0	0	0	3
1926-35	1	3	1	0	0	0	0	0	0	0	5
1916-25	0	4	6	4	2	0	0	0	0	0	16
1906-15	0	4	2	0	1	0	0	0	0	0	7
1896 -5	0	3	0	0	1	0	0	0	0	0	4
1886-95	0	0	0	2	0	0	0	0	0	0	2
1876-85	0	2	0	0	0	0	0	0	0	0	2
1866-75	0	2	0	2	0	0	0	0	0	0	4
1856-65	0	0	0	1	0	0	0	0	0	0	1
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	0	0	0	0	0	0	0	0	0	0	0
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	0	0	0	0	0	0	0	0	0
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	6	24	11	12	4	1	0	0	0	0	58

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	3.00	1.00	0.	1.00	0.	1.00	0.	0.	0.	0.
1956-75	2.00	1.00	0.	1.50	0.	0.50	0.	0.	0.	0.
1946-75	1.67	1.33	0.33	1.00	0.	0.33	0.	0.	0.	0.
1936-75	1.25	1.50	0.50	0.75	0.	0.25	0.	0.	0.	0.
1926-75	1.20	1.80	0.60	0.60	0.	0.20	0.	0.	0.	0.
1916-75	1.00	2.17	1.50	1.17	0.33	0.17	0.	0.	0.	0.
1906-75	0.86	2.43	1.57	1.00	0.43	0.14	0.	0.	0.	0.
1896-75	0.75	2.50	1.38	0.88	0.50	0.13	0.	0.	0.	0.
1886-75	0.67	2.22	1.22	1.00	0.44	0.11	0.	0.	0.	0.
1876-75	0.60	2.20	1.10	0.90	0.40	0.10	0.	0.	0.	0.
1866-75	0.55	2.18	1.00	1.00	0.36	0.09	0.	0.	0.	0.
1856-75	0.50	2.00	0.92	1.00	0.33	0.08	0.	0.	0.	0.
1846-75	0.46	1.85	0.85	0.92	0.31	0.08	0.	0.	0.	0.
1836-75	0.43	1.71	0.79	0.86	0.29	0.07	0.	0.	0.	0.
1826-75	0.40	1.60	0.73	0.80	0.27	0.07	0.	0.	0.	0.
1816-75	0.38	1.50	0.69	0.75	0.25	0.06	0.	0.	0.	0.
1806-75	0.35	1.41	0.65	0.71	0.24	0.06	0.	0.	0.	0.

Table 17

TEN YEAR ACTIVITY RATES

SOURCE REGION OZARK UPLIFT
AREA = 36557 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	4	3	2	0	0	0	0	0	0	0	9
1956-65	4	4	0	0	1	0	0	0	0	0	9
1946-55	0	2	2	3	0	0	0	0	0	0	7
1936-45	1	5	1	3	1	0	0	0	0	0	11
1926-35	2	12	1	0	0	0	0	0	0	0	15
1916-25	2	5	9	0	1	0	0	0	0	0	17
1906-15	0	2	2	0	0	0	0	0	0	0	4
1896 -5	[illegible]	1	0	2	0	0	0	0	0	0	4
1886-95	0	3	0	0	0	0	0	0	0	0	3
1876-85	0	2	4	1	0	0	0	0	0	0	7
1866-75	0	2	0	0	0	0	0	0	0	0	2
1856-65	0	0	0	0	1	0	0	0	0	0	1
1846-55	0	0	0	0	0	0	0	0	0	0	0
1836-45	0	0	0	0	0	1	0	0	0	0	1
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	2	1	0	0	0	0	0	0	0	3
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	14	43	22	9	4	1	0	0	0	0	93

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	4.00	3.00	2.00	0.	0.	0.	0.	0.	0.	0.
1956-75	4.00	3.50	1.00	0.	0.50	0.	0.	0.	0.	0.
1946-75	2.67	3.00	1.33	1.00	0.33	0.	0.	0.	0.	0.
1936-75	2.25	3.50	1.25	1.50	0.50	0.	0.	0.	0.	0.
1926-75	2.20	5.20	1.20	1.20	0.40	0.	0.	0.	0.	0.
1916-75	2.17	5.17	2.50	1.00	0.50	0.	0.	0.	0.	0.
1906-75	1.86	4.71	2.43	0.86	0.43	0.	0.	0.	0.	0.
1896-75	1.75	4.25	2.13	1.00	0.38	0.	0.	0.	0.	0.
1886-75	1.56	4.11	1.89	0.89	0.33	0.	0.	0.	0.	0.
1876-75	1.40	3.90	2.10	0.90	0.30	0.	0.	0.	0.	0.
1866-75	1.27	3.73	1.91	0.82	0.27	0.	0.	0.	0.	0.
1856-75	1.17	3.42	1.75	0.75	0.33	0.	0.	0.	0.	0.
1846-75	1.08	3.15	1.62	0.69	0.31	0.	0.	0.	0.	0.
1836-75	1.00	2.93	1.50	0.64	0.29	0.07	0.	0.	0.	0.
1826-75	0.93	2.73	1.40	0.60	0.27	0.07	0.	0.	0.	0.
1816-75	0.88	2.69	1.38	0.56	0.25	0.06	0.	0.	0.	0.
1806-75	0.82	2.53	1.29	0.53	0.24	0.06	0.	0.	0.	0.

Table 18

TEN YEAR ACTIVITY RATES

SOURCE REGION NEW MADRID A
AREA = 22506 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	15	10	4	1	0	0	0	0	0	0	30
1956-65	11	9	10	0	0	0	0	0	0	0	30
1946-55	8	19	8	5	0	0	0	0	0	0	40
1936-45	5	17	1	2	0	0	0	0	0	0	25
1926-35	6	14	3	1	1	0	0	0	0	0	25
1916-25	0	5	7	1	1	0	0	0	0	0	14
1906-15	0	0	3	3	0	0	0	0	0	0	6
1896 -5	1	2	4	2	2	0	0	0	0	0	11
1886-95	0	9	0	0	0	0	0	0	0	0	9
1876-85	0	1	5	1	1	0	0	0	0	0	8
1866-75	2	4	2	0	0	0	0	0	0	0	8
1856-65	0	2	0	1	1	0	0	0	0	0	4
1846-55	0	1	1	2	0	0	0	0	0	0	4
1836-45	0	3	3	1	0	0	1	0	0	0	8
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	2	0	0	0	0	0	0	0	0	2
1806-15	0	2	0	0	0	0	0	0	2	1	5
SUM MAG	48	100	51	20	6	0	1	0	2	1	229

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.65 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	15.00	10.00	4.00	1.00	0.	0.	0.	0.	0.	0.
1956-75	13.00	9.50	7.00	0.50	0.	0.	0.	0.	0.	0.
1946-75	11.33	12.67	7.33	2.00	0.	0.	0.	0.	0.	0.
1936-75	9.75	13.75	5.75	2.00	0.	0.	0.	0.	0.	0.
1926-75	9.00	13.80	5.20	1.00	0.20	0.	0.	0.	0.	0.
1916-75	7.50	12.33	5.50	1.67	0.33	0.	0.	0.	0.	0.
1906-75	6.43	10.57	5.14	1.86	0.29	0.	0.	0.	0.	0.
1896-75	5.75	9.50	5.00	1.88	0.50	0.	0.	0:	0.	0.
1886-75	5.11	9.44	4.44	1.67	0.44	0.	0.	0.	0.	0.
1876-75	4.60	8.60	4.50	1.00	0.50	0.	0.	0.	0.	0.
1866-75	4.36	8.18	4.27	1.45	0.45	0.	0.	0.	0.	0.
1856-75	4.00	7.67	3.92	1.42	0.50	0.	0.	0.	0.	0.
1846-75	3.69	7.15	3.69	1.46	0.46	0.	0.	0.	0.	0.
1836-75	3.43	6.86	3.64	1.43	0.43	0.	0.07	0.	0.	0.
1826-75	3.20	6.40	3.40	1.33	0.40	0.	0.07	0.	0.	0.
1816-75	3.00	6.13	3.19	1.25	0.38	0.	0.06	0.	0.	0.
1806-75	2.82	5.88	3.00	1.18	0.35	0.	0.06	0.	0.12	0.06

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Table 19

TEN YEAR ACTIVITY RATES

SOURCE REGION NEW MADRID B
AREA = 27506 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	1	0	0	0	0	0	0	0	0	0	1
1956-65	3	4	1	2	0	0	0	0	0	0	10
1946-55	1	2	0	1	0	0	0	0	0	0	4
1936-45	1	3	1	1	0	0	0	0	0	0	6
1926-35	2	5	1	1	0	0	0	0	0	0	9
1916-25	0	6	2	1	0	0	0	0	0	0	9
1906-15	0	3	3	1	0	0	0	0	0	0	7
1896 -5	0	0	1	1	0	0	0	0	0	0	2
1886-95	0	4	1	1	0	0	1	0	0	0	7
1876-85	0	3	3	2	0	0	0	0	0	0	8
1866-75	0	3	0	0	0	0	0	0	0	0	3
1856-65	0	0	0	0	0	0	0	0	0	0	0
1846-55	0	2	0	0	0	0	0	0	0	0	2
1836-45	0	1	0	0	0	0	0	0	0	0	1
1826-35	0	0	0	0	0	0	0	0	0	0	0
1816-25	0	0	1	0	0	0	0	0	0	0	1
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	8	36	14	11	0	0	1	0	0	0	70

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	1.00	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956-75	2.00	2.00	0.50	1.00	0.	0.	0.	0.	0.	0.
1946-75	1.67	2.00	0.33	1.00	0.	0.	0.	0.	0.	0.
1936-75	1.50	2.25	0.50	1.00	0.	0.	0.	0.	0.	0.
1926-75	1.60	2.80	0.60	1.00	0.	0.	0.	0.	0.	0.
1916-75	1.33	3.33	0.83	1.00	0.	0.	0.	0.	0.	0.
1906-75	1.14	3.29	1.14	1.00	0.	0.	0.	0.	0.	0.
1896-75	1.00	2.88	1.13	1.00	0.	0.	0.	0.	0.	0.
1886-75	0.89	3.00	1.11	1.00	0.	0.	0.11	0.	0.	0.
1876-75	0.80	3.00	1.30	1.10	0.	0.	0.10	0.	0.	0.
1866-75	0.73	3.00	1.18	1.00	0.	0.	0.09	0.	0.	0.
1856-75	0.67	2.75	1.08	0.92	0.	0.	0.08	0.	0.	0.
1846-75	0.62	2.69	1.00	0.85	0.	0.	0.08	0.	0.	0.
1836-75	0.57	2.57	0.93	0.79	0.	0.	0.07	0.	0.	0.
1826-75	0.53	2.40	0.87	0.73	0.	0.	0.07	0.	0.	0.
1816-75	0.50	2.25	0.88	0.69	0.	0.	0.06	0.	0.	0.
1806-75	0.47	2.12	0.82	0.65	0.	0.	0.06	0.	0.	0.

Table 20

TEN YEAR ACTIVITY RATES

SOURCE REGION RESIDUAL EVENTS
AREA =6185019 KM**2

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85	SUM DECADE
1966-75	15	13	3	3	0	0	0	0	0	0	34
1956-65	25	16	13	1	0	0	0	0	0	0	55
1946-55	3	29	8	7	0	0	0	0	0	0	47
1936-45	21	26	2	1	0	0	0	0	0	0	50
1926-35	13	24	16	2	1	1	0	0	0	0	57
1916-25	8	16	12	2	0	0	0	0	0	0	38
1906-15	4	11	3	0	2	0	0	0	0	0	20
1896 -5	9	23	9	2	1	0	0	0	0	0	44
1886-95	0	2	1	0	0	0	0	0	0	0	3
1876-85	2	18	2	1	0	1	0	0	0	0	24
1866-75	2	5	2	0	0	0	0	0	0	0	9
1856-65	0	1	1	0	1	0	0	0	0	0	3
1846-55	0	4	2	0	0	0	0	0	0	0	6
1836-45	1	0	1	1	0	0	0	0	0	0	3
1826-35	1	2	0	4	0	0	0	0	0	0	7
1816-25	0	2	0	0	0	0	0	0	0	0	2
1806-15	0	0	0	0	0	0	0	0	0	0	0
SUM MAG	104	192	75	24	5	2	0	0	0	0	402

CUMULATIVE ACTIVITY RATES PER DECADE

YR/MB	2.85 3.35	3.35 3.85	3.85 4.35	4.35 4.85	4.85 5.35	5.35 5.85	5.85 6.35	6.35 6.85	6.85 7.35	7.35 7.85
1966-75	15.00	13.00	3.00	3.00	0.	0.	0.	0.	0.	0.
1956-75	20.00	14.50	8.00	2.00	0.	0.	0.	0.	0.	0.
1946-75	14.33	19.33	8.00	3.67	0.	0.	0.	0.	0.	0.
1936-75	16.00	21.00	6.50	3.00	0.	0.	0.	0.	0.	0.
1926-75	15.40	21.60	8.40	2.80	0.20	0.20	0.	0.	0.	0.
1916-75	14.17	20.67	9.00	2.67	0.17	0.17	0.	0.	0.	0.
1906-75	12.71	19.29	8.14	2.29	0.43	0.14	0.	0.	0.	0.
1896-75	12.25	19.75	8.25	2.25	0.50	0.13	0.	0.	0.	0.
1886-75	10.89	17.78	7.44	2.00	0.44	0.11	0.	0.	0.	0.
1876-75	10.00	17.80	6.90	1.90	0.40	0.20	0.	0.	0.	0.
1866-75	9.27	16.64	6.45	1.73	0.36	0.18	0.	0.	0.	0.
1856-75	8.50	15.33	6.00	1.58	0.42	0.17	0.	0.	0.	0.
1846-75	7.85	14.46	5.69	1.46	0.38	0.15	0.	0.	0.	0.
1836-75	7.36	13.43	5.36	1.43	0.36	0.14	0.	0.	0.	0.
1826-75	6.93	12.67	5.00	1.60	0.33	0.13	0.	0.	0.	0.
1816-75	6.50	12.00	4.69	1.50	0.31	0.13	0.	0.	0.	0.
1806-75	6.12	11.29	4.41	1.41	0.29	0.12	0.	0.	0.	0.

regions. These tables are derived directly from the data given in Tables 1 through 10. In using the data of Tables 11 through 20 to determine the magnitude-recurrence curve, one must examine the data for completeness. For example, consider Table 17 for the Ozark Uplift. All earthquakes of m_b greater than 5 are assumed to have been reported for the entire interval 1806 through 1975. Therefore, the columns for which m_b = 5.35-5.85 and 4.85-5.35 are complete. For m_b = 4.35-4.85 the number of earthquakes per decade is more or less constant back to 1876. Thus the number of earthquakes of that size in a ten-year interval is taken to be 0.90. For m_b = 3.85-4.35 the data are taken to be complete back to 1876, indicating 2.0 earthquakes of that magnitude in a ten-year interval. For m_b = 3.35-3.85 the data are taken to be complete back to 1886, with 4.0 earthquakes per ten-year interval. The magnitude range 2.85-3.35 is taken to be incomplete even to the present. Data for it are not used for the Ozark Uplift or any other source region.

53. Figures 6 through 15 present the magnitude-recurrence data for the ten seismic source regions of the central United States. The data are taken from Tables 11 to 20, after equalizing to 100,000 km^2 and compensating for incompleteness in the data for magnitude less than 5. The curves are straight-line fits to the data, assuming a slope of 0.92 and assigning one-half weight to the largest magnitude data point. Table 21 presents the $\underline{a}$ and $m_{b,max}$ values, as well as the areas of the seismic source regions.

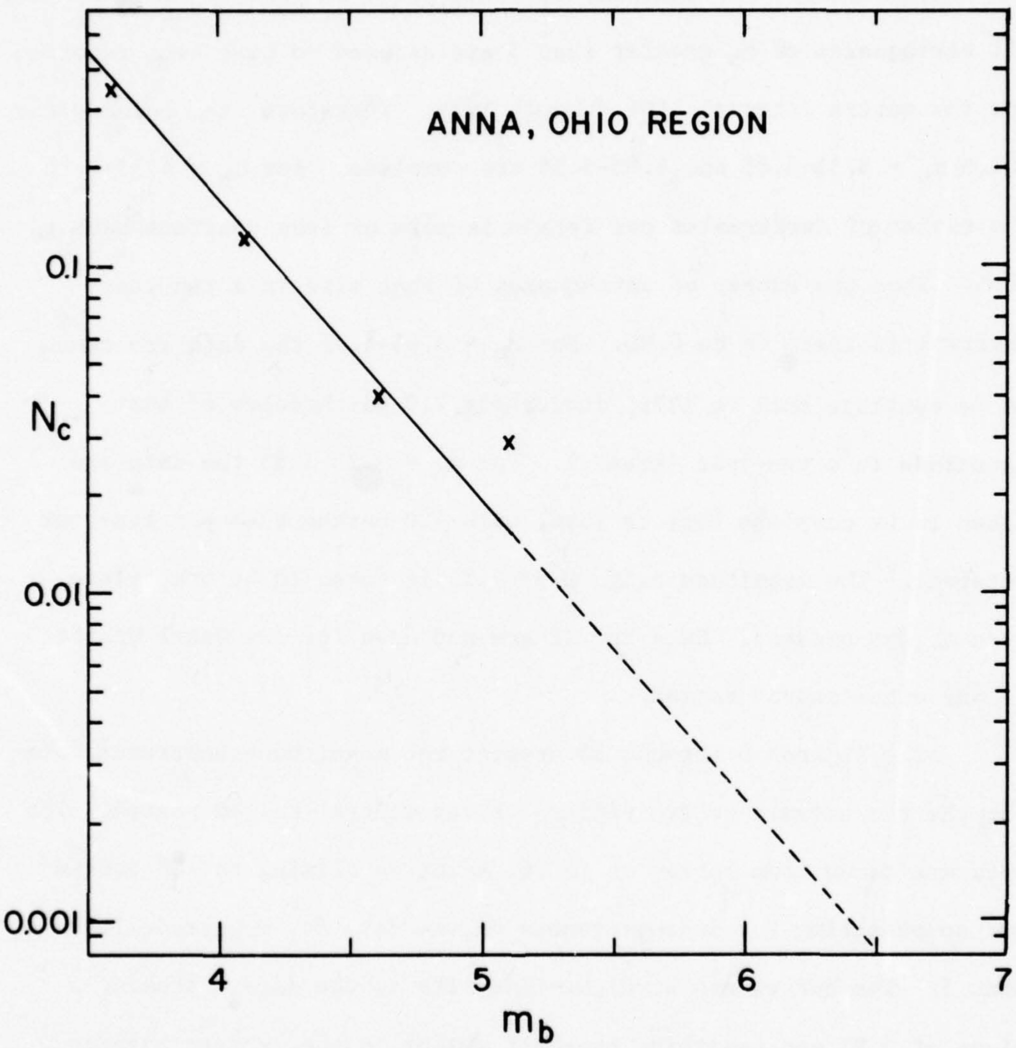

Figure 6. Cumulative magnitude-recurrence curve for the Anna, Ohio region

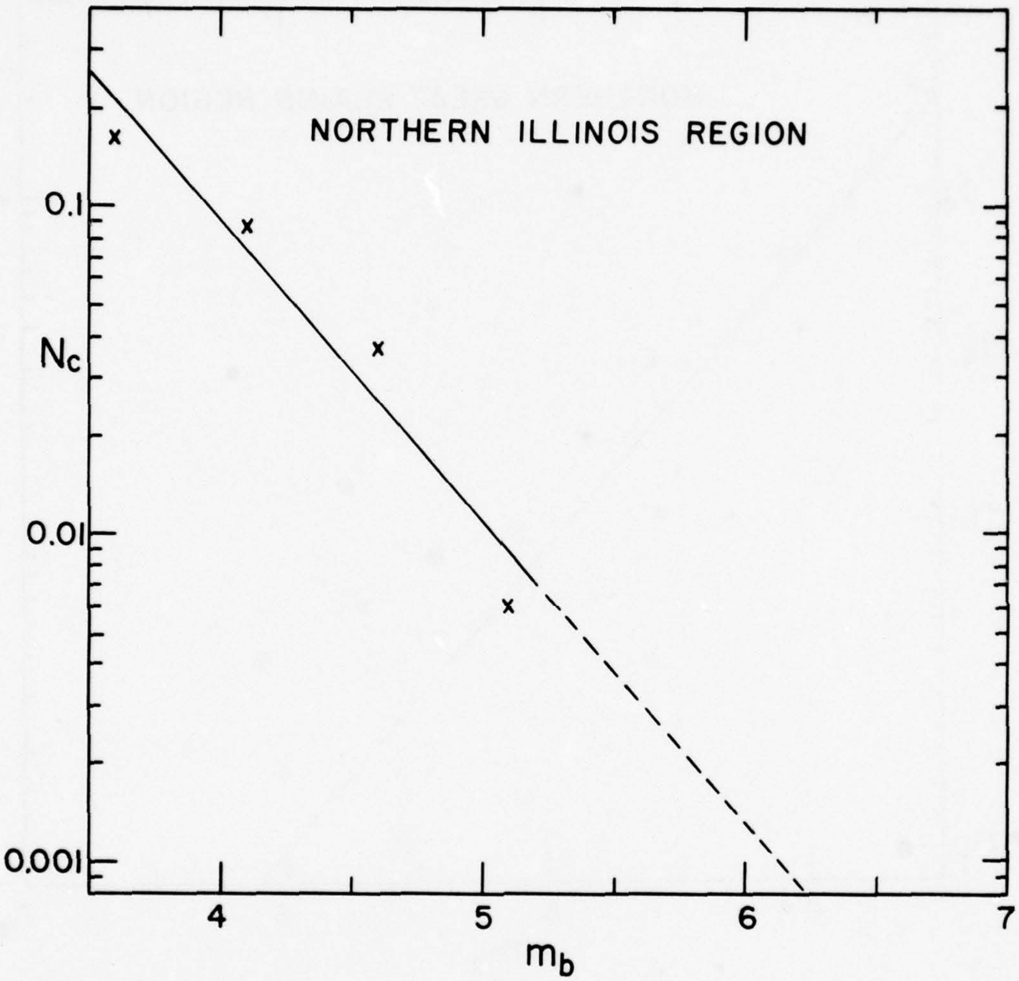

Figure 7. Cumulative magnitude-recurrence curve for the Northern Illinois region

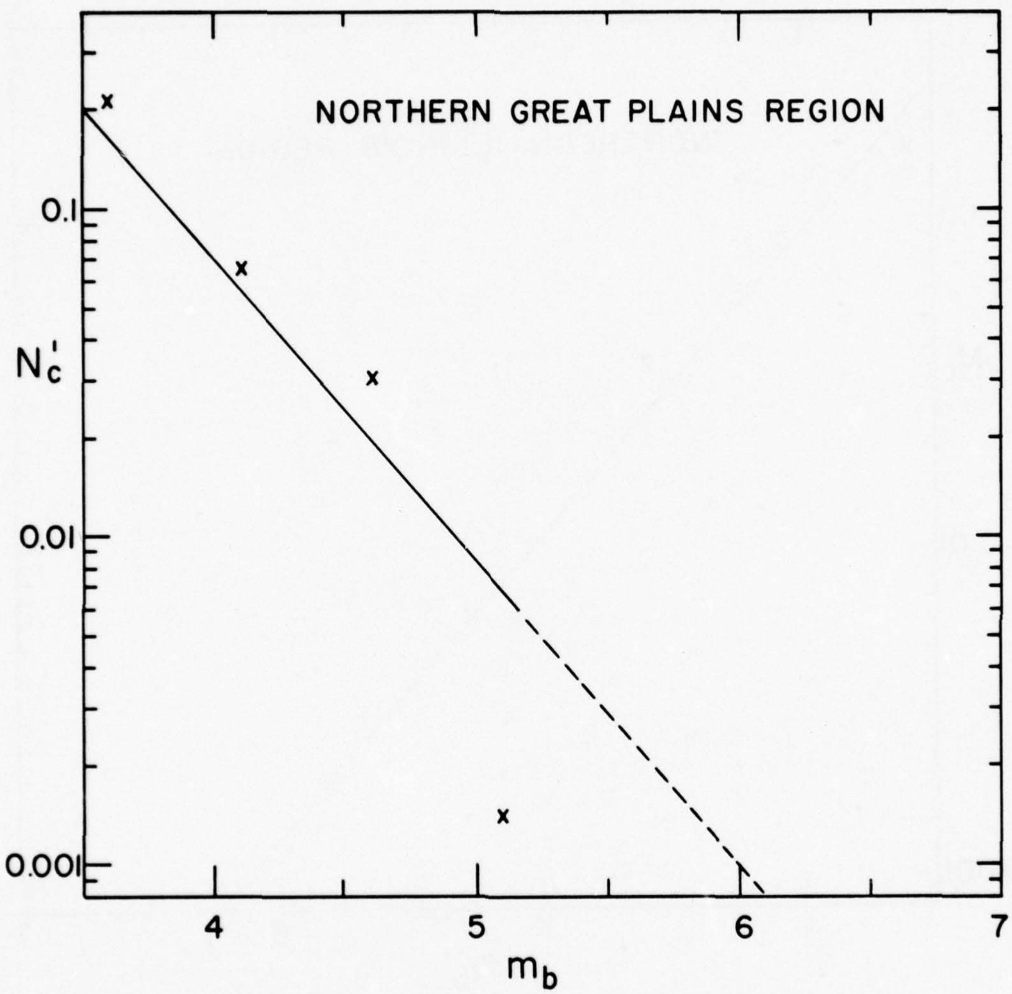

Figure 8. Cumulative magnitude-recurrence curve for the Northern Great Plains region

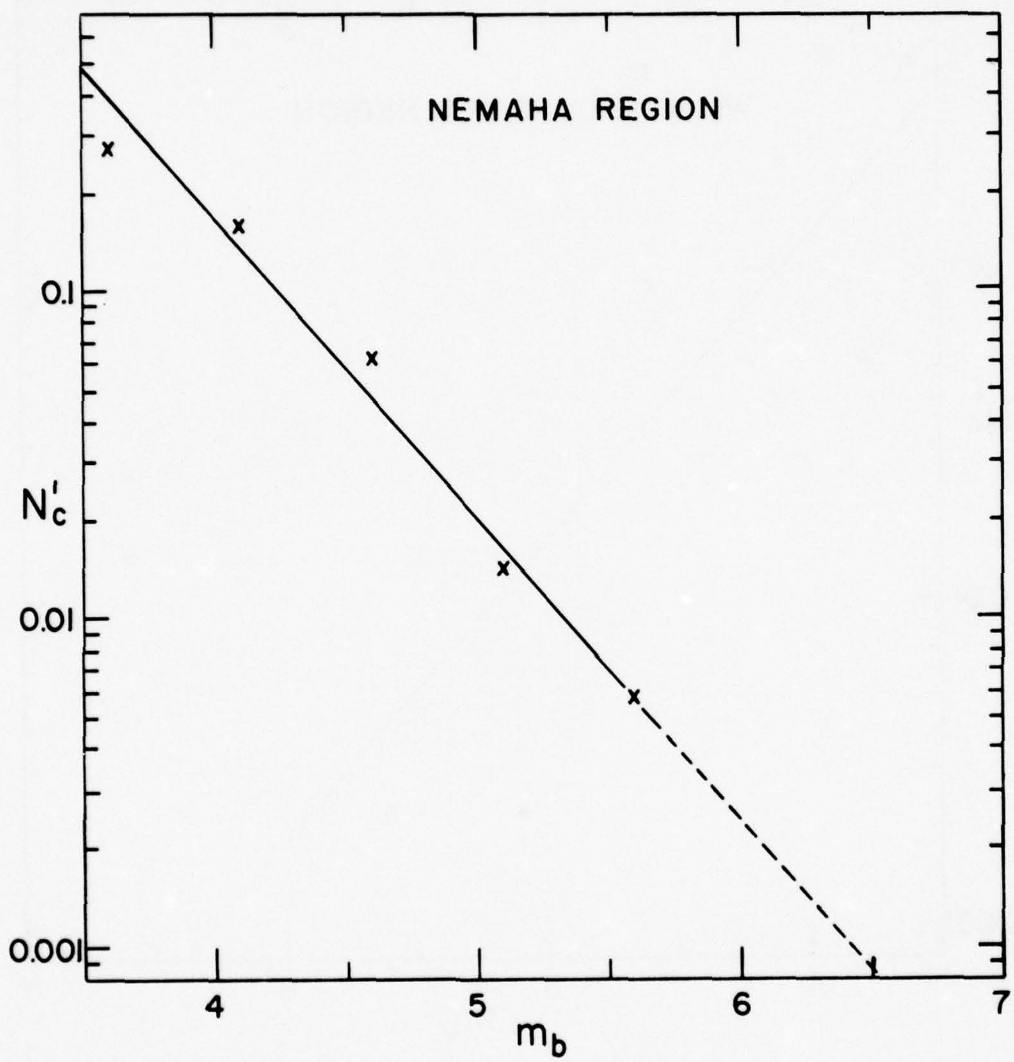

Figure 9. Cumulative magnitude-recurrence curve for the Nemaha region

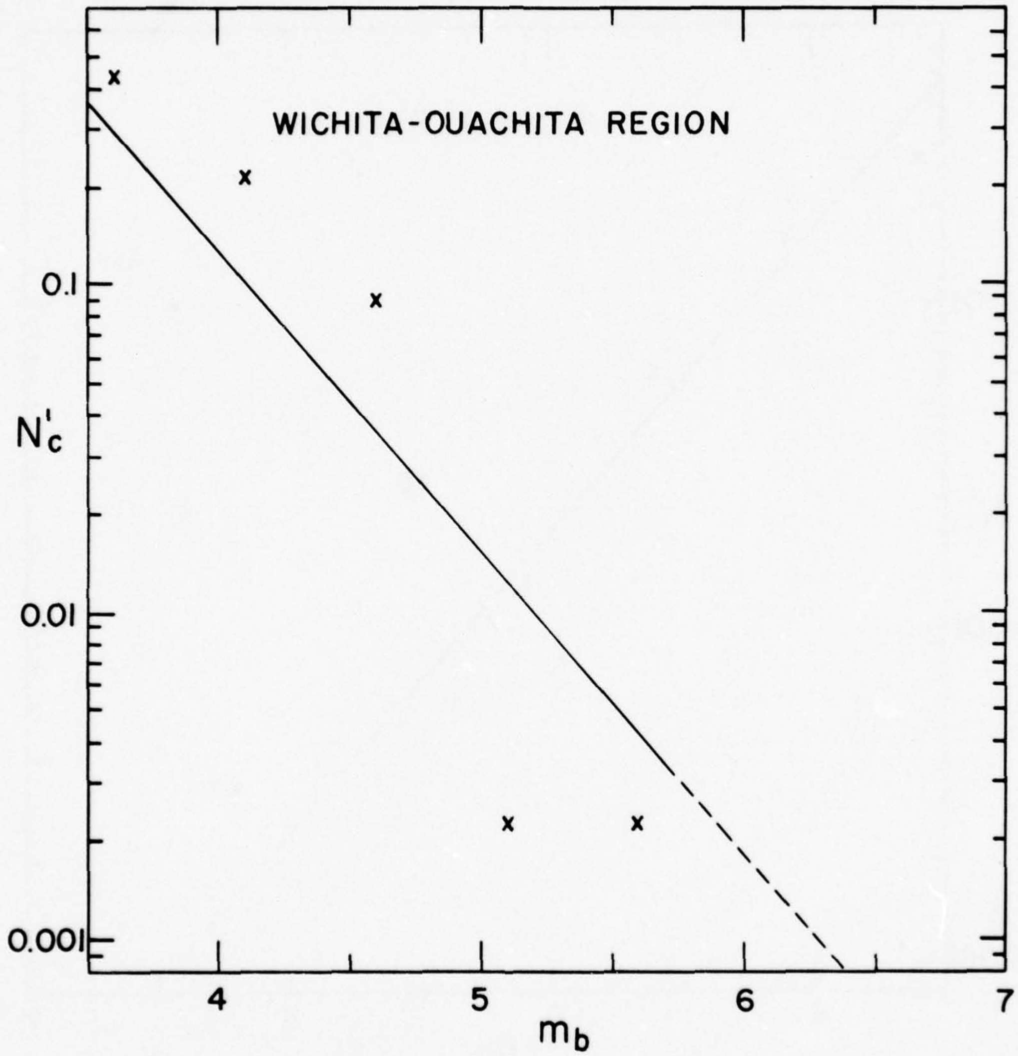

Figure 10. Cumulative magnitude-recurrence curve for the Wichita-Ouachita region

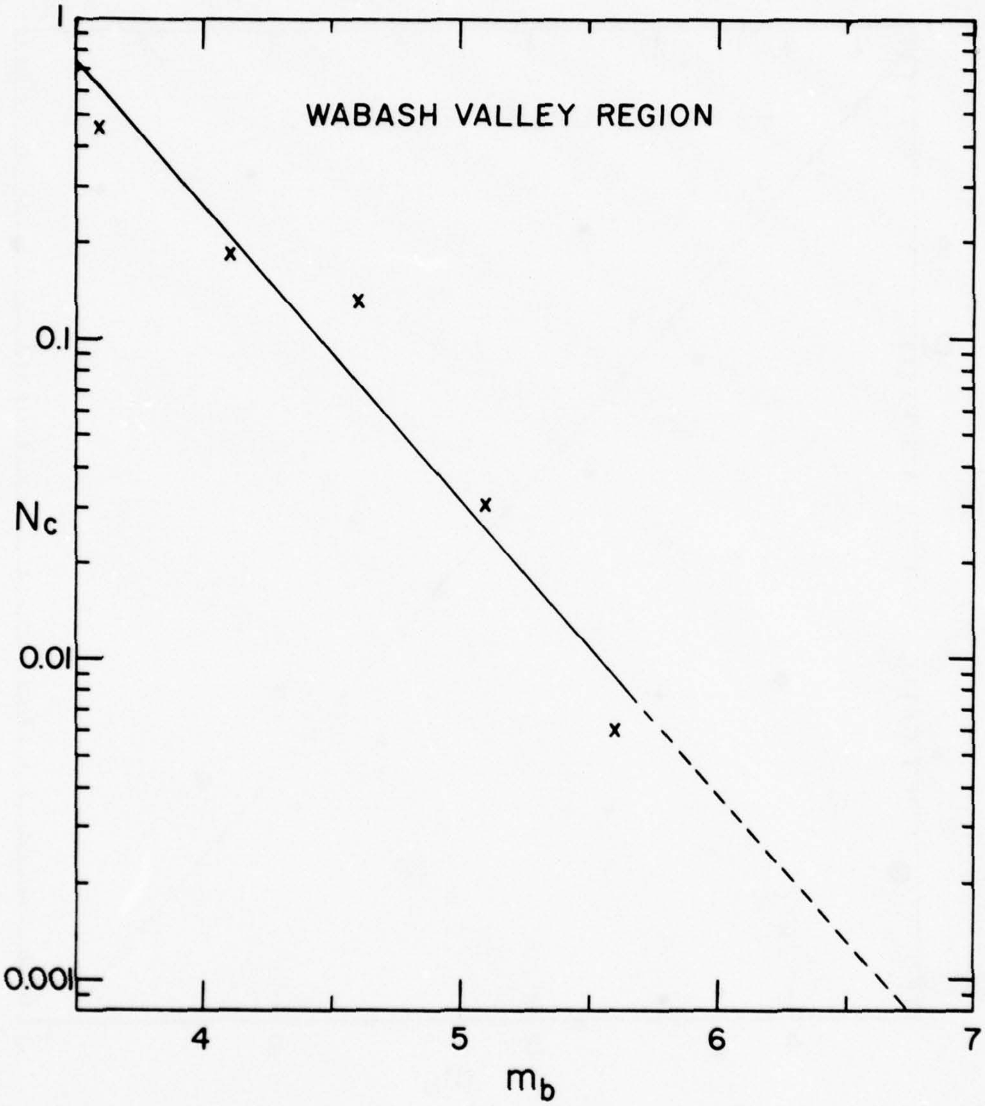

Figure 11. Cumulative magnitude-recurrence curve for the Wabash Valley region

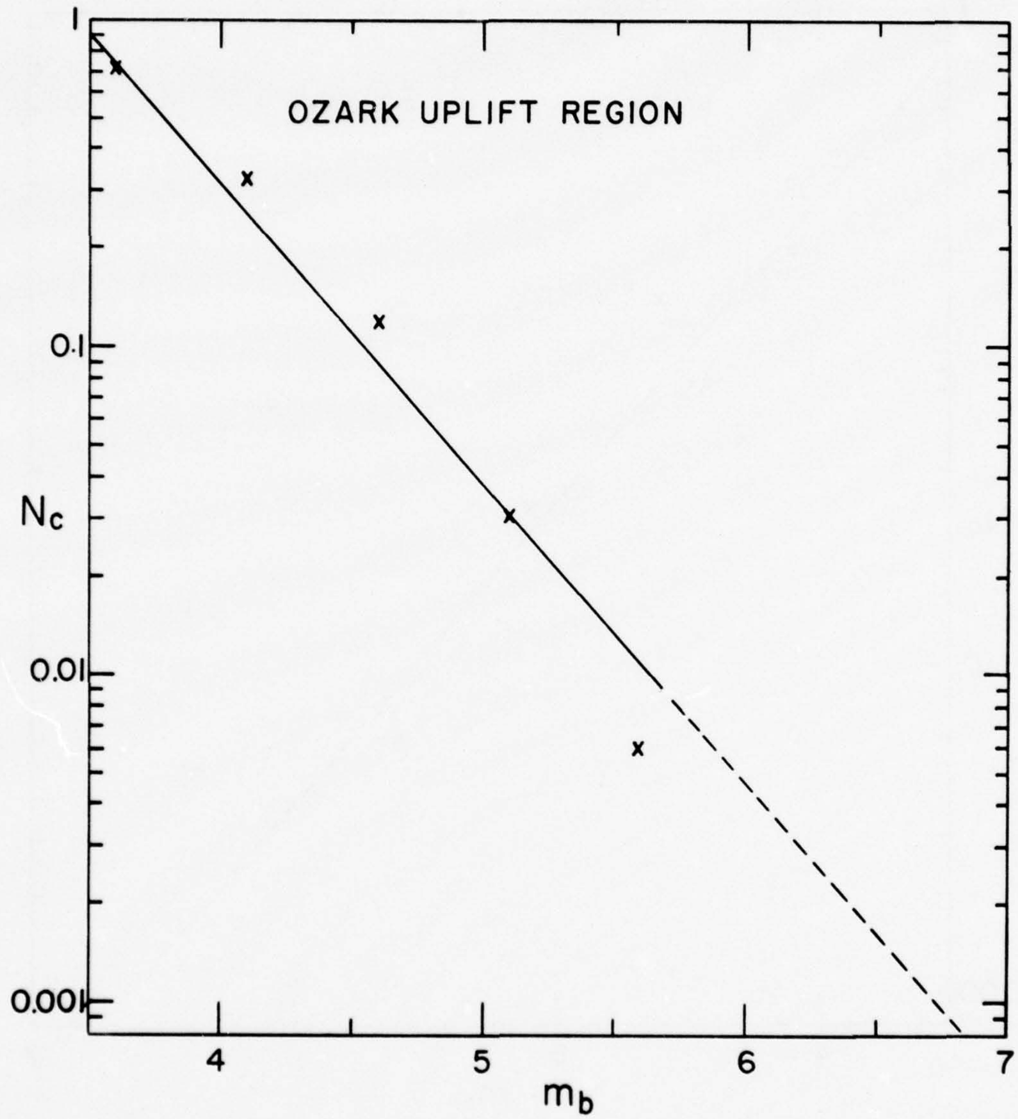

Figure 12. Cumulative magnitude-recurrence curve for the Ozark Uplift region

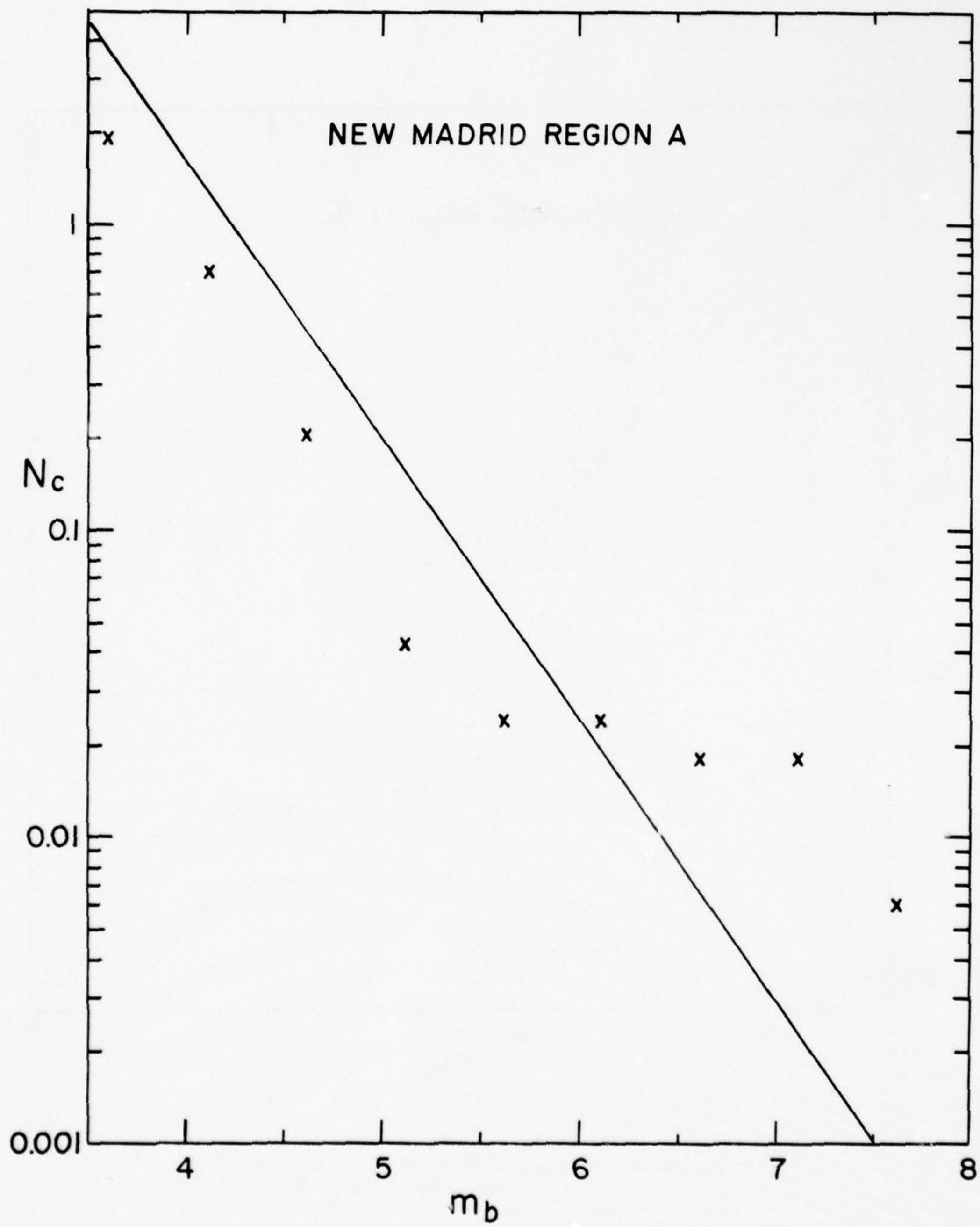

Figure 13. Cumulative magnitude-recurre
New Madrid region

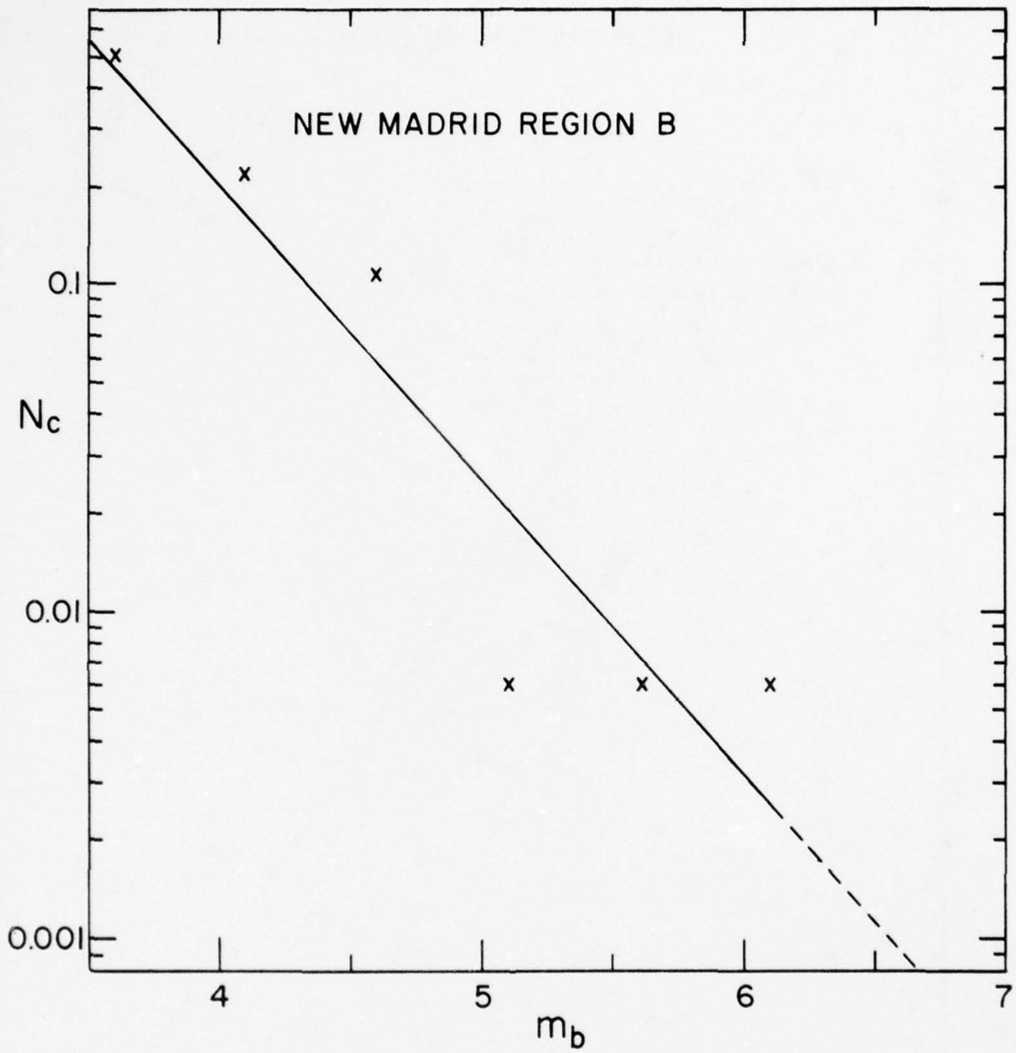

Figure 14. Cumulative magnitude-recurrence curve for New Madrid region B

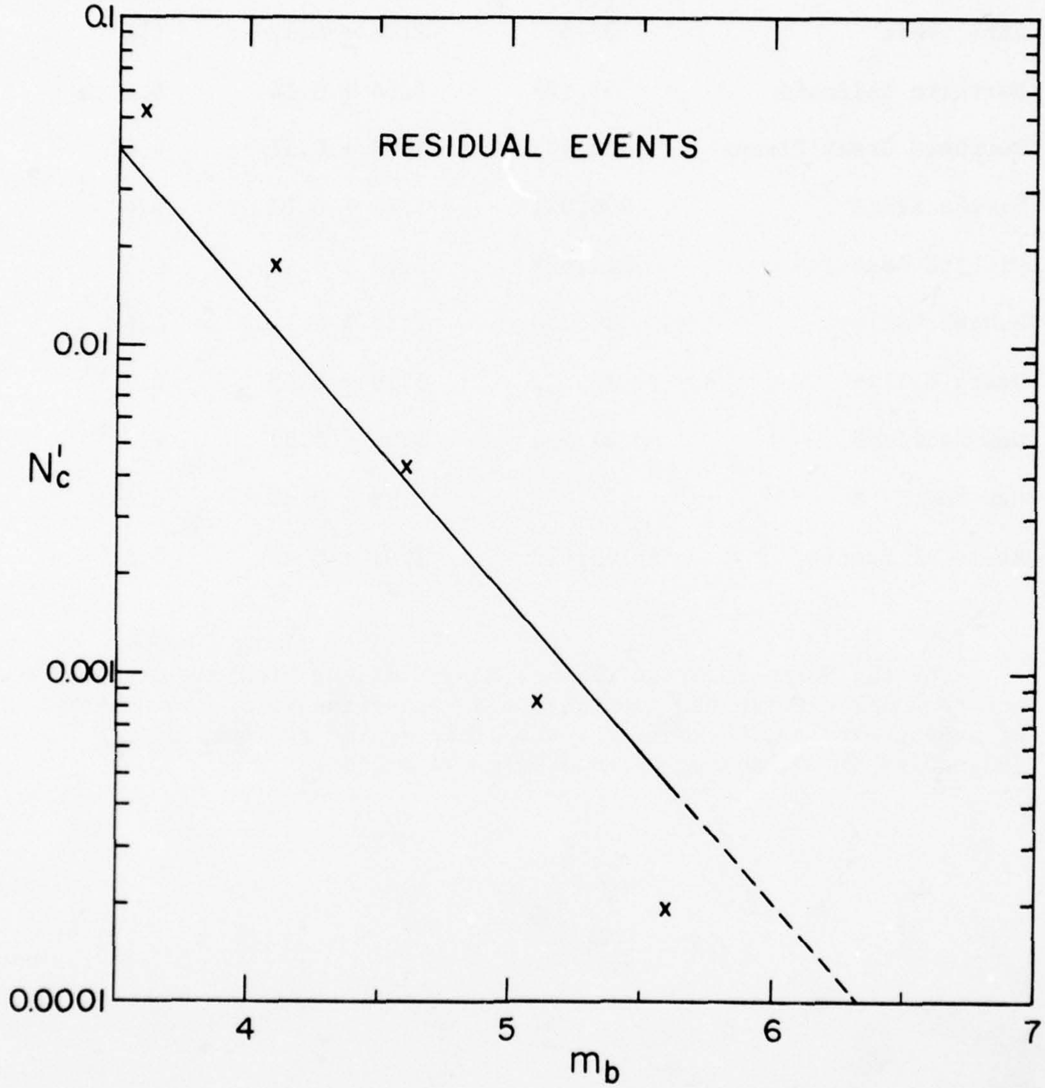

Figure 15. Cumulative magnitude-recurrence curve for the residual events

Table 21
Parameters of Seismic Source Regions

Region	Area (km^2)	a[1]	$m_{b,max}$
Anna, Ohio	37,605	2.82 ± 0.12	6.4
Northern Illinois	55,128	2.64 ± 0.14	6.1
Northern Great Plains	426,723	2.53 ± 0.31	6.0
Nemaha Ridge	206,071	2.91 ± 0.12	6.4
Wichita-Ouachita	261,829	2.79 ± 0.47	6.3
Wabash Valley	39,780	3.10 ± 0.16	6.6
Ozark Uplift	36,557	3.19 ± 0.12	6.7
New Madrid A	22,506	3.90 ± 0.53	7.5
New Madrid B	27,506	2.99 ± 0.30	6.5
Residual Events	6,185,019	1.83 ± 0.21	5.3

[1]For the Northern Great Plains, Nemaha Ridge, Wichita-Ouachita and Residual events, the coefficient a is indicative of the number of events per 100,000 km^2. For the other source regions, a is indicative of the number of events in the region.

Discussion of Maximum-Magnitude Earthquakes

54. Table 21 shows that the New Madrid A seismic source zone is the most active, with a maximum-magnitude earthquake of 7.5. This is the upper limit of the body-wave magnitude scale. That is, no earthquake occurring anywhere in the world will have an m_b greater than 7.5. The New Madrid B region is found to have an $m_{b,max}$ of 6.5, reflecting the lower level of seismicity in that region for the past 170 years. If one argues on a geological basis that there is no reason to suspect that a large earthquake cannot occur at the ends of the New Madrid fault zone, then regions A and B should be combined into a single source region. This gives an $m_{b,max}$ of 7.5, but with a recurrence period of 800 years instead of 1400 years. Russ[22], from a study of fault displacement of recent sediments in western Tennessee near Reelfoot Lake, concludes that the recurrence period for major earthquakes in the New Madrid region is about 666 years. Thus geologic data obtained from trenching of recent sediments are in fairly good agreement with the seismicity data.

55. The Ozark Uplift seismic source region consists of a portion of the Illinois basin and the St. Francois highlands of southeast Missouri. The seismicity data do not indicate any separation into two distinct source regions. If such, however, happened to be the case, the maximum-magnitude earthquake for each of the two regions would be about 6.4. Because there is as yet no compelling seismological or

geological reason to separate them into two distinct zones, the more conservative approach of combining them into a single zone with $m_{b,max}$ of 6.7 is adopted here.

56. For the remainder of the seismic source zones the approximate boundaries appear fairly well established, although they may be subject to variation as more earthquake data become available in the future. The maximum-magnitude estimates, however, as given in Table 21 are likely to remain unchanged.

PART V: SPECIFICATION OF BEDROCK MOTION

57. The specification of ground motion in the central United States is very difficult due to the lack of an adequate strong-motion data base upon which to develop empirical correlations between strong ground-motion parameters and some measure of earthquake size, such as maximum Modified Mercalli intensity, I_o, or body-wave magnitude, m_b. Reports by Krinitzsky[23] and Krinitzsky and Chang[24] discuss the current strong-motion data base in the western United States, present some correlations and also contain references to other works. The problem of the validity of estimating strong ground motion in the central United States on the basis of the western United States data base still exists.

Maximum Acceleration

58. As an attempt at estimating strong ground-motion acceleration in the central United States, some recent empirical results by Murphy and O'Brien[25] and theoretical work by Herrmann[26] will be used to construct a relationship between acceleration, magnitude and distance for the central United States.

59. Using a data set of nearly 1500 strong-motion accelerograms, Murphy and O'Brien[25] performed a number of correlations between acceleration, site intensity, magnitude and distance. Correlations were made using vertical components of ground motion as well as the two horizontal components of ground motion. Lacking original accelerogram traces, they made no attempt to rotate the horizontal data into radial or tangential components of motion. Each horizontal observation was treated as an individual data point.

60. Murphy and O'Brien[25] found that the correlation between maximum acceleration and site intensity is distance dependent (as noted by Krinitzsky and Chang[24]), and that the error distribution about the predicted accelerations is log-normal with one standard deviation corresponding to a factor of 2 to 2.5. On the basis of residual studies, they proposed a relationship between maximum horizontal acceleration, a, site intensity, I_{MM}, magnitude, M, and epicentral distance, R, of the form

$$\log_{10} a = a\, I_{MM} + b\, M + c \log_{10} R + d. \qquad (1)$$

61. Murphy and O'Brien[25] found that this relationship reduced the log-normal standard deviation for maximum horizontal accelerations to a factor of 2.0. They also found that the coefficient "d" exhibited a regional dependence. Their particular relationship used in this study is

$$\log_{10} a_H(\mathrm{cm/sec}^2) = 0.14\ I_{MM} + 0.24\ M - 0.68\ \log_{10} R + K, \quad (2)$$

where K will be adjusted to fit strong-motion data obtained from earthquakes in the New Madrid seismic zone by Herrmann[14].

62. To apply Equation (2) to the central United States, the following relationships are used:

$$I_o = 2\ m_b - 3.5, \qquad (3)$$

as given by Nuttli[4], where I_o is the maximum Modified Mercalli intensity of an earthquake with body-wave magnitude m_b;

$$I_{MM} = \begin{cases} 0.0 + I_o - 0.00\ \log_{10} R, & R \leq 20\ \mathrm{km} \\ 3.1 + I_o - 2.46\ \log_{10} R, & R \geq 20\ \mathrm{km} \end{cases} \qquad (4)$$

where I_{MM} is the site intensity at a distance R kilometers from a source with maximum intensity I_o. This simple relationship approximates the relation given by Gupta and Nuttli[27]. Combining Equations (3) and (4), one obtains

$$
I_{mm} = \begin{cases} -3.5 + 2\ m_b - 0.00\ \log_{10} R, & R \le 20\ \text{km} \\ -0.4 + 2\ m_b - 2.46\ \log_{10} R, & R \ge 20\ \text{km} \end{cases} \tag{5}
$$

Equations (2) and (5) give

$$
\log_{10} a_H\ (\text{cm/sec}^2) = \begin{cases} -1.26 + 0.52\ m_b - 0.00\ \log_{10} R + K, & R \le 15\ \text{km} \\ -0.06 + 0.52\ m_b - 1.02\ \log_{10} R + K, & R \ge 15\ \text{km} \end{cases} \tag{6}
$$

63. In the derivation of Equation (6), special consideration was given for $R<20$ km. This is due to the fact that the Murphy and O'Brien[25] correlation had few data points closer than 20 km and because theoretical wave-propagation studies by Herrmann[26] indicate that the change in the coefficient of geometrical spreading occurs at a distance of about one source depth, which is at most 15 km for the central United States, as shown by Herrmann[13]. An equivalence of m_b and M was assumed since the Murphy and O'Brien[25] data set is skewed toward $M<6.5$, for which the equivalence holds.

64. Since Equation (6) depends heavily upon the validity of the Murphy and O'Brien correlation, Equation (6) should not be accepted without some discussion of its applicability. It is almost axiomatic that one can fit any data by multiple regression if one uses enough parameters. The real question at hand is whether the coefficients obtained from the analysis are physically meaningful. The coefficient of geometrical spreading in Equation (6) indicates that the maximum

acceleration attenuates as approximately R^{-1} at large distances. This is theoretically seen in the work by Herrmann[26] for non-attenuating media. Nuttli and Dwyer[15] have shown that, for all practical purposes, anelastic attenuation is minimal for frequencies less than 10 Hz for the central United States out to at least 300 km. Thus the geometrical spreading of Equation (6) is both theoretically and empirically acceptable for the region.

65. The numerical value of the coefficient of the magnitude, m_b, requires some consideration. First of all, most correlations show a weak dependence of maximum acceleration upon magnitude, with a tendency of higher accelerations for larger earthquakes. Thus the coefficient 0.52 is not unreasonable. Studies based on the theoretical work of Herrmann[26] show that constant stress drop earthquakes are approximately characterized by constant acceleration when the peak accelerations of the constant stress drop earthquakes are compared at the same distance. In seismological terms, at distances greater than a few source dimensions from the earthquake, the Fourier amplitude spectrum of the ground displacement is characterized by a flat level from $f = 0$ Hz to $f = f_c$, the corner frequency. At frequencies greater than f_c, the amplitude spectrum varies as $(f/f_c)^{-\gamma}$, where γ is a positive number. Usually, $\gamma = 2$. Earthquakes with constant stress drop are such that the zero-frequency spectral level, $A(f = 0)$, and the corner frequency vary such that $A(f = 0)\ f_c^{\ 3}$ = constant. If γ is

less than 3, there is a relationship between $A(f = 0)$ and magnitude, even though the stress drop is constant.

66. In a study of larger earthquakes of eastern North America recorded by seismographs since 1910, Street and Turcotte[19] noted that the stress drops increased by a factor of ten, from 6 bars to 60 bars, over a range of seismic moments (proportional to $A(f = 0)$) from 1.0 E23 dyne-cm to 1.0 E27 dyne-cm. The corner frequency for the seismic moment M_o = 1.0 E23 dyne-cm is about 0.6 Hz. It is not difficult to show, given $\gamma = 2$ and the fact that m_b measures 1-Hz spectral amplitudes, that an increase in stress drop of a factor of ten is accompanied by a change of two units in m_b. Thus, using some simple arguments of spectral scaling together with inferences from theoretical studies, log a_H is proportional to 0.5 m_b, and the coefficient of m_b in Equation (6) is acceptable on theoretical as well as observational grounds.

67. Thus the coefficients in Equation (6) are reasonable for application to the central United States. It remains to evaluate the coefficient K. The central United States strong-motion data base given by Herrmann[14] consists of nine three-component accelerograms from three earthquakes with m_b of 4.2, 4.5 and 5.0. Data were plotted in the manner of Murphy and O'Brien[25] and visually fitted to Equation (6). The data from all 18 horizontal traces were used. The value of $K = 0.7$ provides a suitable fit. Murphy and O'Brien[25] obtained $K = 0.6$ for western United States data. The fact that these two

values differ by only 0.1 units indicates that there is some similarity in earthquake processes and indicates that a main difference between the western and central United States strong motion is primarily due to differences in anelastic attenuation.

68. Another way of using Equation (6) is to obtain a value of K which describes the maximum vectorial horizontal acceleration. Visually, one obtains K = 0.9. Figure 16 shows the central United States strong-motion data, together with theoretical curves based upon Equation (6), for several magnitudes. Since Equation (4) overestimates intensities for distances greater than 300 km, and due to the distance range of data used in the Murphy and O'Brien[25] correlations, the curves are shown as dashed lines beyond 300 km. For magnitudes greater than $m_b = 5$, accelerations are not specified at shorter distances due to the lack of observations in the central United States, as well as to the neglect of the effect of fault dimensions upon the geometrical spreading factor, which is controlled by focal depth solely for small magnitude earthquakes. Another reason is due to the difficulty of specifying the ground-motion spectrum at short distances.

69. The recommend relation for maximum horizontal acceleration for the central United States is

$$\log_{10} a_H \ (\mathrm{cm/sec^2}) = \begin{cases} -0.36 + 0.52\, m_b - 0.00 \log_{10} R & R \leq 15 \text{ km} \\ 0.84 + 0.52\, m_b - 1.02 \log_{10} R & R \geq 15 \text{ km} \end{cases} \qquad (7)$$

with a standard error of estimate corresponding to a factor of about 2.0.

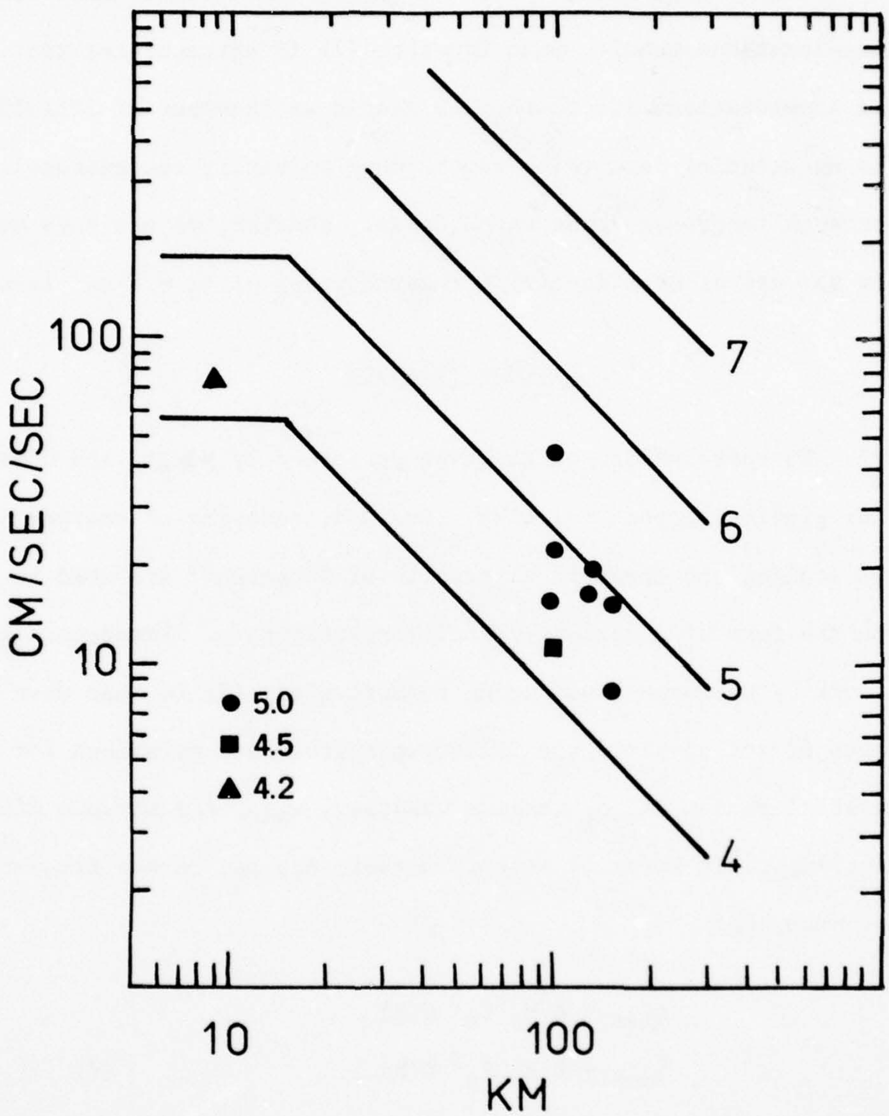

Figure 16. Central United States acceleration relation (Equation (7)) as a function of magnitude, m_b. Observed data from Herrmann[14]

70. Equation (7) was based on data from earthquakes and accelerograph sites in the Mississippi embayment. Thus Equation (7) may not in fact represent bedrock motions. It is also of interest to note that large accelerations result when Equation (7) is extrapolated to estimate accelerations due to the New Madrid earthquakes of 1811-1812. There is no existing data which can be used to verify the extrapolations to such large magnitude earthquakes. However, we can have confidence in the use of Equation (7) for earthquakes of $m_b = 6$ and less.

Maximum Velocity

71. No correlations of the type performed by Murphy and O'Brien[25] exist for predicting peak velocity. Instead, concepts of source-spectrum scaling and theoretical results of Herrmann[26] are used to estimate the form of a maximum-velocity relationship. Extensions based on the work by Herrmann[26] and using reasoning similar to that used in Paragraphs 62 and 63 yield the following approximate relations for maximum acceleration, a_{max}, maximum velocity, v_{max}, and maximum displacement, d_{max}, in terms of seismic moment, M_o, and corner frequency of the source, f_c:

$$\begin{aligned} a_{max} &= A\, M_o\, f_c^{\,3}\, G(R) \\ v_{max} &= B\, M_o\, f_c^{\,2}\, G(R) \qquad (8) \\ d_{max} &= C\, M_o\, f_c\, G(R) \end{aligned}$$

where the geometrical spreading factor G(R) is defined as

$$G(R) = \begin{cases} 1.0 & R \leq R_o \\ (R/R_o)^{-1} & R \geq R_o \end{cases} \qquad (9)$$

If the source spectrum is assumed to have a high frequency asymptote of f^{-2}, and assuming that $f_c < 1$ Hz, the following relationships immediately follow for $R \geq R_o$

$$\begin{aligned} \log_{10} a_{max} &= D + 0.5\, m_b - 1.0 \log_{10} R \\ \log_{10} v_{max} &= E + 1.0\, m_b - 1.0 \log_{10} R \qquad (10) \\ \log_{10} d_{max} &= F + 1.5\, m_b - 1.0 \log_{10} R \end{aligned}$$

Implicit in this derivation are the assumptions that m_b is directly proportional to the logarithm of the source-spectrum level at f = 1 Hz, and also that the basic shape of the faulting displacement as a function of time is the same, except for simple time scaling.

72. As an attempt to test this theoretical relation, curves of maximum horizontal velocity are plotted as a function of distance in Figure 17. The coefficient E was chosen to fit through the m_b = 5 data of the 25 March 1976 earthquake in the New Madrid seismic zone. Equation (10) is strictly valid only for regions for which anelastic attenuation is small; otherwise it would remain valid only at shorter distances, preferably less than 60 km. Keeping this in mind, some California strong-motion data are plotted as a further test of the hypotheses of Paragraph 68. The m_b values estimated by Nuttli et al[2] were used for

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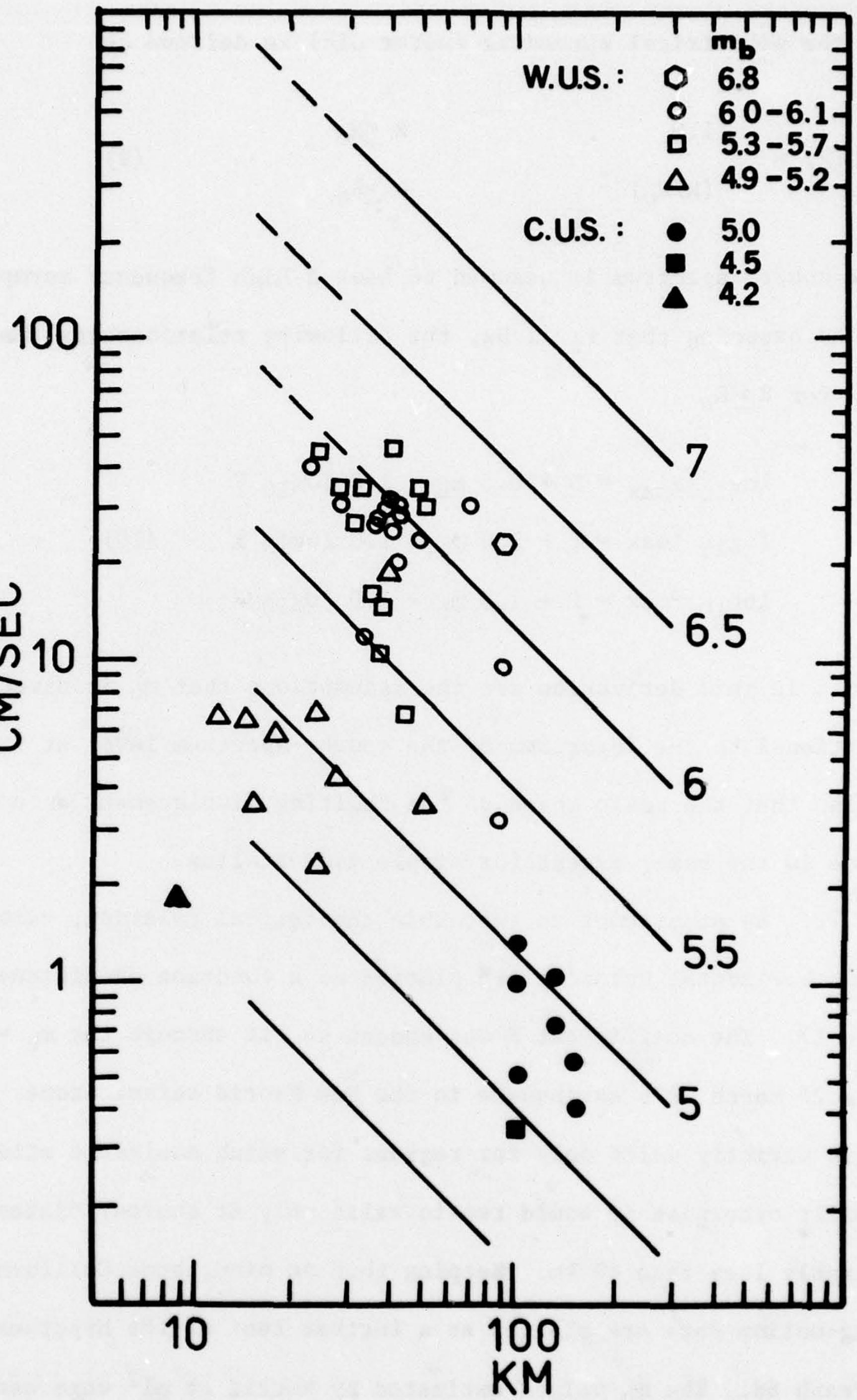

Figure 17. Maximum horizontal velocity as a function of distance and m_b (Equation (10)). Solid symbols are central United States data and closed symbols are selected western United States data, as a function of m_b

these earthquakes. The California strong-motion data are taken from a compilation by Chang[28].

73. The theoretical curves were fitted to the central United States data, which defined E = 2.92 in Equation (10). Only a fraction of the data in Chang[28] was plotted. The immediate conclusion is that the relation

$$\log_{10} v_{max} \text{ (cm/sec)} = -2.92 + 1.0\, m_b - 1.0 \log_{10} R \qquad (11)$$

fits the data quite well. Unfortunately, there are few data for $m_b = 7$. The Kern County, $m_b = 6.8$, earthquake is anomalous in that it has low ground motion velocities, perhaps indicating that it is a low stress drop event. An extrapolation of Equation (11) to $m_b > 6.5$ must be tested with real data from other sources, before one can feel comfortable in applying it to the central United States. Further work needs to be done in order to estimate the statistical confidence limits on the coefficients of Equation (11) as well as to estimate the log-normal standard deviation.

Maximum Displacement and Duration

74. A possible relation for peak horizontal displacement is given in Equation (10). However, the maximum displacements usually published in catalogs of strong-motion records are ordinarily contaminated by processing errors. Further research must be done on this point before displacement data can be used.

75. The duration of strong ground motion is difficult to specify because of differences in the basic definition of "duration." No statement on duration and its dependence upon magnitude and distance can be made for the central United States at the present time. Theoretical work, now in progress, on the lines of Herrmann[26] may shed light on this parameter in the near future. At present, the best that can be done would be to use duration estimates based upon western United States strong motion data.

PART VI: SUMMARY AND CONCLUSIONS

76. The catalog of central United States earthquakes contained in Part III gives the date, origin time, epicentral latitude and longitude, epicentral intensity, felt area and body-wave magnitude for all known earthquakes strong enough to be felt and/or of m_b greater than or equal to 3 which occurred since 1800. Statistical tests indicate the catalog is complete for all earthquakes of m_b greater than 5. For lesser magnitude earthquakes the time interval for which the catalog is complete varies with source region and with magnitude.

77. A time interval extending back to 1800 is too short to ensure that the maximum-magnitude earthquake has occurred during it. That is, for most of the seismic source regions it is unlikely that the largest earthquake that can and will occur in the source region has happened since 1800. Thus there is a need to be able to predict the maximum-magnitude earthquake from the last 175 years of data. To do

this, it was assumed that the New Madrid region and the Charleston, South Carolina region have experienced their maximum-magnitude earthquakes in historic times, the former in 1811-1812 and the latter in 1886. These earthquakes were removed from the population of earthquakes which occurred in the two source regions since 1800, and magnitude-recurrence curves were constructed with the remaining data. In each case the extrapolation of these curves to a recurrence time of 1000 years gave a magnitude close to the observed magnitudes of the 1811-1812 and 1886 earthquakes. By this line of reasoning it is inferred that extrapolation of the recurrence curves for other source regions will give the maximum-magnitude earthquake when the recurrence time is 1000 years. (A recurrence time of 1000 years means that there is a 63% probability an earthquake of that size will occur within a 1000-year interval.) In this manner maximum-magnitude earthquakes were estimated for each of the seismic source regions of the central United States, as well as for the remaining area which is called the Residual region. The results are given in Table 21.

78. A recent paper by Ahorner and Rosenhauer[29] on seismic risk in the Upper Rhine graben of Germany and Switzerland also supports the contention of this report that the one-in-a-thousand year earthquake is a reasonable choice for the maximum-magnitude earthquake. Using a six-hundred year historical record of earthquakes, they proceed one step further and assign a zero probability to the occurrence of the extrapolated one-in-a-thousand year earthquake.

79. One of the principal purposes of this report is to give formulas which can be used to compute maximum acceleration and maximum velocity in bedrock for earthquakes of various magnitudes in the central United States. The desired relations are given by Equations (7) and (11). Figures 16 and 17 give plots of the equations, and present the results in graphical form. Equations (7) and (11) are derived relations, based in part upon theoretical formulations and in part upon observational data. The basic approach is to assume that $\log_{10} a_H$, where a_H is maximum horizontal acceleration, is proportional to the body-wave magnitude, m_b, and to $\log_{10} R$, where R is epicentral distance. The coefficients and the constant in the resulting equation are evaluated using the existing strong-motion data for central United States earthquakes. The results, for horizontal distances greater than the source depth, are shown to be consistent with what is known of attenuation in the region and with the manner in which the stress drop depends on seismic moment in the central United States. Thus, the empirical Equation (7) is shown to be consistent with theory, taken together with observational evidence on attenuation and seismic source-spectrum scaling. Equation (11) for maximum velocity was developed from a theoretical knowledge of the behavior of the seismic source spectrum, with the constant in the equation chosen to fit the velocity data of the $m_b = 5$ earthquake of 25 March 1976 in the New Madrid seismic zone. Figure 17 shows that the resultant velocity-distance-magnitude equation also closely satisfies the California strong-motion

velocity data for earthquakes of m_b from 4 to 6.5. The scatter of the data points from the curves of Figure 17 is relatively small, and serves as a measure of the degree of uncertainty attached to Equation (11).

80. Data are lacking for strong-motion accelerations resulting from large magnitude earthquakes at near distances. For such a case it is necessary to consider the complex nature of the extended fault rupture process. Because of this the curves of Figure 16 are not extended to distances of less than 25 km for $m_b = 6$ earthquakes and to distances of less than about 40 km for $m_b = 7$ earthquakes. Resolution of this problem can only come when the ground motion of large magnitude earthquakes is recorded by accelerographs in the near field. Near-field data for the central United States can be expected to be similar to those for the western United States or other tectonic source zones because anelastic attenuation, which is the chief cause of differences in ground motion between the regions at larger epicentral distances, is unimportant at small distances.

81. In addition to collecting more strong-motion data for the central United States, it would be desirable to be able to more accurately outline the boundaries of the seismic source zones. This can be done by microearthquake and by geological studies. Progress towards the solution of this problem, as well as on accumulating more strong-motion data, will be slow, however, because of the relative infrequency of earthquakes in the central United States. Until that time it will be necessary to evaluate, on an individual basis, the

maximum-magnitude earthquake for sites near the boundaries of the seismic source zones.

82. The objective of this report has been to provide as complete a catalog of earthquakes as possible for the central United States, to determine the rate of seismic activity as well as seismic potential for the region, and to recommend new relations for the scaling of strong ground motion. The results of this report should be directly applicable for probabilistic risk analysis without much modification. On the other hand, direct use of these data in a deterministic approach must be tempered with caution because of the large areal extent of the source regions defined and the lack of observable causative faults in the region. The maximum-magnitude earthquake is defined as the one-in-a-thousand year earthquake for the entire source region. For deterministic studies, recognizing the small chance that this event will lie under the structure site, a smaller earthquake for design purposes should be chosen. Krinitzsky and Chang[24] have taken a conservative approach to this problem of the so-called "floating earthquake" by assuming that it can occur at the site, but have used their far-field relations between MM intensity and ground acceleration, velocity and displacement to estimate the site motion. Other possible approaches might be to use the one-in-a-hundred year earthquake as the maximum credible earthquake at the site, or to assume the magnitude of the maximum credible earthquake at the site is one unit less than that for the extended source region.

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APPENDIX A: Source Region Coordinates

1. The polygonal source regions are described by specifying their corners in terms of latitude and longitude pairs. For consistency, these corners are ordered such that each successive pair is the next corner, when one progresses clockwise about the source region.

   a. Anna, Ohio: (39.5, 85.0), (41.5, 85.0), (41.5, 85.0), (41.5, 83.0), (39.5, 83.0)

   b. Northern Illinois: (41.0, 91.0), (43.0, 91.0), (43.0, 88.0), (41.0, 88.0)

   c. Northern Great Plains: (41.0, 104.0), (47.0, 104.0), (47.0, 96.0), (41.0, 96.0)

   d. Nemaha Ridge: (34.0, 100.0), (41.0, 98.0), (41.0, 95.0), (34.0, 97.0)

   e. Wichita-Ouachita: (35.0, 103.0), (37.0, 103.0), (35.0, 90.0), (33.0, 90.0)

   f. Wabash Valley: (39.0, 88.0), 39.6, 87.5), (39.6, 86.5), (38.5, 87.0), (36.5, 88.0), (37.5, 89.5)

   g. Ozark Uplift: (37.0, 91.5), (39.0, 89.5), (38.5, 88.5), (35.5, 91.5)

   h. New Madrid A: (35.5, 91.0), (37.0, 89.5), (36.5, 88.5), (35.0, 90.0)

   i. New Madrid B: (35.5, 91.5), (37.5, 89.5), (36.5, 88.0), (34.5, 90.0) less region covered by New Madrid A.

   j. Residual: (25.0, 110.0), (50.0, 110.0), (50.0, 80.0), (25.0, 80.0) less regions delineated above.

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